Ecological Indicators xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Agriculture, climate change and sustainability: The case of EU-28

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ARTICLE INFO

Keywords:
Agriculture and environment
Evaluation of environmental effects
Sustainability
Panel data models

ABSTRACT

Agriculture and climate change are characterized by a complex cause-effect relationship. The agricultural sector generates significant quantities of gas emissions that affect climate. The rise in the concentration of greenhouse gases in the atmosphere, the increase in temperatures as well as changes in the precipitation regime have repercussions on the volume, quality and stability of the agricultural and zoo technical production, but also on the natural environment in which agriculture is practiced. Based on the above, the purpose of the paper is twofold. Firstly, through the Wroclaw Taxonomic Method, we construct a composite indicator, called the Index of Sustainable Agriculture (ISA), and analyse 28 countries that have joined the European Union from 1 July 2013 to today (EU-28) over the period 2005–2014, according to 16 variables. Secondly, the Granger-causality test for panel data is implemented in order to verify the causal relationship among the ISA, climate change and agricultural production. In other words, we test which of the three analyzed variables turns out to be the cause variable and which, instead, turns out to be the effect variable. Furthermore, we test if there is a bidirectional causality among the variables. This analysis provides a wide overview on how European countries rank according to the ISA and its three crucial pillars, i.e. environmental, economic and social. Moreover, important causality relationships among the ISA, climate changes (approximated by mean annual temperature and mean annual precipitation and provided by the Climate Research Unit (CRU) Time-Series (TS) Version 3.22 of the University of East Anglia) and agricultural production (approximated by wheat and spelt yields and provided by EUROSTAT) are identified. In particular, the following hypotheses are verified: 1) there is a negative bidirectional relationship between climate change and agricultural yields; 2) there is a negative bidirectional causal relationship between climate change and sustainable agriculture; 3) conventional agriculture negatively affects sustainable agriculture.

1. Introduction

During the past century, global climate change has entailed rising temperatures and so heat waves and droughts; increasing in precipitation, storms and floods risk; higher levels of carbon dioxide in the atmosphere (OECD, 2016a). These both climate and human-induced changes have created major challenges for attaining sustainability through the depletion of natural resources. Moreover, they can worsen agricultural yields vulnerability (Waggoner, 1983; Smith et al., 1996; Adams et al., 1998; Hall et al., 2006; Tebaldi and Lobell, 2008; Nelson et al., 2009; Maleksaeidi and Karami, 2012; Gliessman, 2015). Agriculture in fact, is highly exposed to climate change, as its activities directly depend on climatic conditions. However, the effects of climate change on agricultural yields vary by country and by crop (Adams et al., 1998). Some areas could benefit from the action of some components of climate change (e.g. cool countries with rising temperatures or "*carbon fertilization effects*" (Stokes and Howden, 2010)); other countries could suffer significant adverse effects (e.g. water stress, increasing in the variability of yield, reduced crop yields etc.). In various countries, in fact, a combination of different types of these impacts can exacerbate vulnerabilities (Adger, 2006; Füssel, 2007). For instance, increasing in temperature could have both positive and negative effect on agricultural yields, the direction of the effect depends on the characteristics of a country. Nevertheless, a severe rising temperature implies water scarcity which may worsen agricultural systems in all countries especially the semi-arid areas – as Southern European countries. In this case,

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https://doi.org/10.1016/j.ecolind.2018.04.064
Received 29 June 2017; Received in revised form 23 April 2018; Accepted 25 April 2018
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a negative relationship between increasing in temperature and agricultural yields has been hypothesized. In addition, increasing in precipitation may benefit semi-arid areas by increasing soil moisture, but could worsen problems in areas with water excess. Whilst, a reduction in rainfall could have the opposite effects. In irrigated areas the negative impact of changed precipitation and increased temperatures is reduced by the availability of irrigation water, making yields more resistant to climate variation. In this last case, groundwater and rivers are the mitigation factors of climate variability. In summary, every climate change component has more than one effect and the prevalence of one type of biophysical effect depends on the soil condition, the species, and type of plant.

Another stream of literature highlights how agriculture contributes to climate change through greenhouse gases emissions (GHGs) that trap heat in the atmosphere. In particular, agricultural sector generates direct GHGs emissions through (i) nitrous oxide emissions from soils, (ii) applications of fertilizers, (iii) dejections from grazing animals, (iv) methane production by ruminant animals, and indirect GHGs emissions due to land-use changes, including land clearing and deforestation (Hall et al., 1996; Delmas et al., 1997; Tilman et al., 2002). However, agriculture can also contribute to climate change mitigation by reducing greenhouse gas emissions and by sequestering carbon while maintaining food production. The direction of these effects depends on the type of agricultural practices.

In the past half-century, with the growing demand for food, farming systems have had to increase their production. Although, with some difference in the various countries, the general trend was the intensification and the industrialization of crop system in order to increase output per hectare. This mainly has occurred through (i) increased agricultural area (Scherr and McNeely, 2008); (ii) genetically modified crops; (iii) low crop rotation; (iv) intensive irrigation; (v) intensive monoculture, where labour inputs are minimized and technology-based inputs are maximized (as fertilizers and artificial pesticides). The improper application of fertilizers and pesticides as well as the use of irrigation water and agricultural machinery land have led to considerable environmental harm (as climate change) (Victor and Reuben 2002; Lin, 2011; Tilman et al., 2002; Pretty et al. 2003; Goulding et al. 2008; Gliessman, 2005). As shown by Pretty (2008), the relationship between intensive cultivation and chemical pesticides has been particularly strong. For these reasons, a negative effect of an increase in agricultural yield per hectare of land (intensive crops) on climate change has been hypothesized. Many of the same problems occur when farmers plant large areas to organic monocultures (Gliessman, 2015). Monocultures lead to easier spread of diseases and pests thereby decreasing resilience to climate change variability that often induces additional stress on plants (Lin, 2011). In the light of that, the following two hypotheses are tested:

H1: Climate change causes the agricultural yields and probably in a negative way.
H2: The agricultural yields have a negative effect on climate change.

H1 and H2 allow us to hypothesize a bidirectional causal relationship between agricultural yield and climate change.

However, following the increasing social pressure and the EU's high emissions reduction targets, agriculture could also contribute to climate change mitigation by reducing greenhouse gas emissions and by sequestering carbon while maintaining food production (European Union Committee, 2010). In this case, we refer to sustainable agriculture. The concept of sustainability has been debated in response to concerns about the adverse environmental and economic effects of conventional agriculture (Pretty, 1995). Sustainable agriculture differs from conventional agriculture as regarding both the use and the management of resource, nature of inputs, cultural practices, methods of plant protection (Pretty, 1995; Tilman et al., 2002; Gliessman 2005, 2015). Sustainable agriculture makes efficient use of on-farm resources, effectively uses knowledge, conservatively uses skills of farmers to improve their self-reliance and capacities and minimally uses the external and non-renewable inputs to the extent that these are deficient in the natural environment (Pretty, 1995; Pretty et al. 2000). In particular, we define "*sustainable agriculture as practices that meet current and future societal needs*" (Pretty, 2008) for food, for ecosystem services, and for healthy lives. An *egoistic* and *myopic* economy is aimed at intensive agriculture with negative effects on climate change. On the contrary, an *altruistic* and *far-sighted* economy aims at an intelligent use of natural resource and at safeguarding the equilibrium of the ecosystem for future generations. Consequently, a positive effect of sustainable agriculture on climate and its variability is expected. In other word, an increasing of sustainable agriculture would reduce climate change (negative effect).

Furthermore, greater sustainability implies resource-conserving technologies and practices that can be used to improve the stocks and use of natural capital as well as less intensive agriculture (i.e., more sustainable use of resources, less pesticides and fertilizers). For instance, sustainable agriculture would result in a reduction in the application of pesticides and fertilizers (i.e., Lewis et al., 1997; Hassanali et al., 2008; Bale et al., 2008) with uncertain effects on agricultural yield. Some studies show how pesticide application can be reduced (thought pest control techniques) without negative effects on yield (Lewis et al., 1997; Brethour and Weerskink, 2001; Hassanali et al., 2008). Pretty (2008) shows four possible scenarios of the effects of pest control techniques on yields: (i) pesticide application and yields increase; (ii) pesticide application increases, but yields decline; (iii) both pesticide application and yields fall; (iv) pesticide application declines, but yields increase. "*The (iii) cases, where yields fall slightly while pesticide use falls dramatically, are mainly cereal-farming systems in Europe, where yields typically fall to some 80% of current levels while pesticide use is reduced to 10–90% of current levels*" (Pretty, 2008, p. 458). However, it would be useful to highlight, as suggested by Tisdell (1996), that non-use of inorganic chemicals is not sufficient to qualify agriculture as sustainable. Based on the results of previous studies, the following two hypotheses are proposed:

H3: There is a negative bidirectional causal relationship between climate change and sustainable agriculture.
H4: Conventional agriculture negatively causes sustainable agriculture.

The aim of our study is to test those research hypotheses, in order to provide to policy-makers the appropriate information to promote agricultural sustainability and environmental protection. Particularly, a two-step empirical analysis is implemented. First, through the Wroclaw Taxonomic Method, an index of Sustainable Agriculture (ISA) is computed. There are many empirical works that measure agricultural sustainability through the use of diverse indicators, but few are those on the impact of climate change. Second, by the Granger-causality test for panel data, the causal relationship among the ISA, climate change (proxy by mean annual temperature (°C) and mean annual precipitation (mm)) and the agricultural production (proxy by wheat and spelt yield) is verified. Granger causality is a way to investigate causality between two or more variables. Causality is closely related to the idea of cause-and-effect. In other words, causality is the relationship between two variables, one being the *cause variable* and the other being the *effect variable*. There are two types of causality relationship between these variables, bidirectional causality and unidirectional causality. In unidirectional causality, the *cause variable* causes the *effect variable* and not vice versa. In bidirectional causality, the *cause variable* causes the *effect variable*; however, at the same time, *effect variable* also causes *cause variable*. This means that both reactions can take place simultaneously (see Granger, 1969; Leamer, 1985; Cromwell et al., 1994; Hoover, 2001). In addition, we use a GMM-system estimator in order to verify the sign of the relationship among these three variables. For these

proposes EUROSTAT data for 28 European countries[1], corresponding to the European level NUTS1, over the period from 2005 to 2014 are taken into account. In addition, climate variables are obtained from the Climate Research Unit (CRU) Time-Series (TS) Version 3.22 of the University of East Anglia.

The rest of the paper is organized as follows. Section 2 presents the methods. Section 3 discusses data and variables, stressing the literature that supports the use of such variables. Section 4 shows the empirical findings whereas Section 5 is devoted to discussions. Section 6 concludes.

2. Material and methods

2.1. First step: Wroclaw Taxonomic method

Literature suggests several methods to aggregate pillars into a composite index (see OECD, 2008). In this study the Wroclaw Taxonomic Method is implemented. This method was first designed in the early '50s by Polish mathematicians belonging to the Wroclaw Graduate School of Economics (Florek et al, 1951). The resulting composite indicator is based on the sum of the Euclidean distances that separate the individual countries (units) from an "ideal country", normalized by a measure of variability of these distances. Thus, countries can be ordered in proportion with the distance from the optimum situation. The first systematic application of this methodology was due to Harbison et al. (1970). Afterwards, it has been applied to the construction of economic and social indicators. Among the huge class of aggregation methods, the Wroclaw method exhibits several advantages: firstly, for each variable, the benchmark depends on its distribution (this implies that it is data-driven and not arbitrary given); secondly the computation is very easy since the aggregation function is the Euclidean distance. In addition, adding new years, for instance as allowed for by data availability, the values of the indices for the previous years do not change. This is also true if a new country, whose values of the variables are less or equal to the reference values, are added. Thus, for each year, the construction of the overall ISA is computed with a two-step procedure. Firstly, a composite indicator for each pillar is constructed by applying the Wroclaw Taxonomic to the variables belonging to that pillar. Then, an overall indicator is computed by applying the same methodology to the three pillars. More in detail, let x_{ij}^t be the value of the j-th indicator (for $j \in \{1,...,16\}$, $k = 16$) across the i-th European country ($i \in \{1,...,28\}$, $n = 28$) at time $t \in \{2008,...,2014\}$. In addition, we denote by $X \in \mathbb{R}^{n,k,t}$ the generic 3-dimensional matrix representing the distribution of the indicators for the 28 European countries over time.

For a fixed year t, we calculate the normalized matrix, denoted as Z as follows:

$$z_{ij}^t = \begin{cases} \frac{x_{ij}^t - \bar{x}_j^t}{\sigma_j^t} & \text{positively correlated with the indicator} \\ -\frac{x_{ij}^t - \bar{x}_j^t}{\sigma_j^t} & \text{negatively correlated with the indicator} \end{cases} \quad (1)$$

where $\bar{x}_j^t$e σ_j^t are, respectively, the mean and the standard deviation of the j-th indicator, that is

$$\bar{x}_j^t = \frac{1}{n}\sum_{i=1}^{n} x_{ij}^t \text{ and } \sigma_j^t = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{ij}^t - \bar{x}_j^t)^2}.$$

By applying this transformation, each indicator, $z_{.j}^t$ has mean equal to 0 and standard deviation equal to 1 and in this way, differences due to the scale of measurement don't matter. In addition, all the indicators are now positively related with the phenomenon.

As stressed before, the Wroclaw procedure requires the choice of a referent point, the so-called "ideal country" to compute the distance. As stressed by, Mazziotta and Pareto (2017), the identification of the "ideal unit" represents the main weakness of this methodology (see Silvio-Pomenta, 1973 for more details). While for the variables involved in the Europe 2020 strategy[2] the optimal value is known since the targets to achieve are predetermined, for our indicators a precise definition of what would be the optimal value is not available. Therefore, for each year, the maximum value for each indicator is considered. As a consequence, our methodology depends on the distribution of our indicators. Of course, this choice could be not without criticisms since comparisons over time are not well-defined.

Thus, for all the indicators and for each year, we compute the maximum value that is the benchmark for the indicator.

$$m_j^t = \max_i z_{ij}^t \quad (2)$$

Then, for each statistic unit and for each year, the Euclidean distance between all the normalized values and such maximum reads as:

$$e_i^t = \sqrt{\sum_{j=1}^{m}(z_{ij}^t - m_j^t)^2} \quad (3)$$

Thus, denoting with $e^t = \frac{1}{n}\sum_{i=1}^{n} e_i^t$ and $\sigma(e^t) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(e_i^t - e^t)^2}$ respectively the mean and the standard deviation, the Wroclaw index at time t is:

$$W_i^t = \frac{e_i^t}{e^t - 2\sigma(e^t)} \quad (4)$$

The index takes value equal to 0 if the distance between a given country and the reference one is zero, that is if the country reaches the maximum value in all the pillars; whereas the index increases as the country is far from the reference.

However, this definition for W_i^k seems a bit counterintuive since as the index increases we are far from an optimal situation in which all the countries show better performances. Thus, the complement to the maximum achieved in each year of the indicator is computed as follows:

$$ISA_i^t = \max_t W^t - W_i^t \quad (5)$$

2.2. Second step: Granger-causality test and GMM-system estimator

The Granger-causality test allows us only to determine the causal relationship among the ISA, climate change and agricultural production and not the magnitude of the impact (see Dietrich, 2012; Crociata et al., 2015). In particular, the Granger-causality test verifies the power of a variable to predict another one (Hamilton, 1995), *i.e.* to check whether y is Granger caused by x. In other words, we regress y on its own lagged values and on those of x and test whether the set of coefficients associated with x are statistically different from zero (Agovino, 2014). The procedure used to test the causality relationship in a panel data set has been suggested by Holtz-Eakin et al. (1988) and implemented in several papers (Hsiao, 1986; Weinhold, 1996; Nair-Reichert and Weinhold, 2001; Choe, 2003; Crociata et al., 2015). The Granger causality test for panel data is expressed by:

[1] Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, United Kingdom, Austria, Finland, Sweden, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania and Croatia.

[2] Europe 2020 is a 10-year strategy proposed by the European Commission that Member States should take to boost growth and employment for the current decade. It defines five goals and, for each of them it identifies a threshold, that is a minimum level to be achieved. The headline targets concern: 1) the raise of the employment rate of the population aged 20–64 (at least at 75%); 2) the increase in the investment rate on R&D (3% of the GDP); 3) the reduction of greenhouse gas emissions (at least 20% compared to 1990 levels), the increase in both the share of renewable energy in final energy consumption (to 20%) and energy efficiency (20%); 4) the reduction of the share of early school leavers (from the 15% to 10%) and the increase in the percentage of population aged 30–34 having completed tertiary (at least 40%); 5) the reduction of poverty, lifting 20 million of European people out of poverty. The achieved results are annually monitored to (see Bley et al., 2017).

$$y_{it} = \alpha_0 + \sum_{j=1}^{m} \alpha_j y_{it-j} + \sum_{j=1}^{m} \delta_j x_{ij-t} + f_i + u_{it} \quad (6)$$

where $i = 1,\ldots,N$ are the observation units (countries) and $t = 1,\ldots,m$ represents the time index. The model in differences (Eq. (7)) allows us to eliminate the fixed effects (f_i):

$$y_{it} - y_{it-1} = \alpha_0 + \sum_{j=1}^{m} \alpha_j (y_{it-j} - y_{it-j-1}) + \sum_{j=1}^{m} \delta_j (x_{it-j} - x_{it-j-1}) + (u_{it} - u_{it-j-1}) \quad (7)$$

This specification introduces a simultaneity bias because the error term is correlated with $y_{it} - y_{it-1}$. In this case it is possible to get a consistent estimate applying the Two-Stage Least Squares (2SLS) regression analysis.

In order to verify whether x causes y it is necessary to test the joint hypothesis H_0: $\delta_1 = \delta_2 = \ldots = \delta_n = 0$. If the null hypothesis is rejected, then x Granger-causes y.

Finally, in order to know the sign of the relationship among the ISA, climate change and agricultural production, the following four equations are estimated:

$$ISA_{it} = \alpha_0 + \beta ISA_{it-1} + \sum_{j=1}^{3} \gamma_j W\&S_{it-j} + \sum_{j=1}^{3} \delta_j MAT_{it-j} + \sum_{j=1}^{3} MAP_{it-j} + \lambda_t + \mu_i + u_{it} \quad (8)$$

$$W\&S_{it} = \alpha_0 + \beta W\&S_{it-1} + \sum_{j=1}^{3} \gamma_j ISA_{it-j} + \sum_{j=1}^{3} \delta_j MAT_{it-j} + \sum_{j=1}^{3} MAP_{it-j} + \lambda_t + \mu_i + u_{it} \quad (9)$$

$$MAT_{it} = \alpha_0 + \beta MAT_{it-1} + \sum_{j=1}^{3} \gamma_j W\&S_{it-j} + \sum_{j=1}^{3} \delta_j ISA_{it-j} + \sum_{j=1}^{3} MAP_{it-j} + \lambda_t + \mu_i + u_{it} \quad (10)$$

$$MAP_{it} = \alpha_0 + \beta MAP_{it-1} + \sum_{j=1}^{3} \gamma_j W\&S_{it-j} + \sum_{j=1}^{3} \delta_j MAT_{it-j} + \sum_{j=1}^{3} ISA_{it-j} + \lambda_t + \mu_i + u_{it} \quad (11)$$

where the ISA is the composite indicator of sustainable agriculture, $W\&S$ is the wheat and spelt yield (tons per hectare). W&S is chosen since it is the variable with the fewest value per country. In order to verify whether W&S is a good proxy for agricultural production, we regress W&S on total agricultural production (tons per hectare) by fixed effect model (see Hsiao, 1986). Regardless of the high number of missing values, we verify that the parameter associated with total agricultural production has an expected positive sign and is statistically significant at 1%. Finally, the R^2 overall (i.e., the weighted average of the between and within R^2) is equal to 0.88: 88% of the variance of W& S is explained by the total agricultural production. This result allows us to conclude that W & S is a good proxy for total agricultural production.

MAT and *MAP* are the proxy variables of climate change. u_{it} is the stochastic error term, μ_i is the country fixed effect, λ_t is the temporal fixed effect.

The estimation of this model faces several problems. First, by using panel data, OLS coefficients are biased when country fixed effects are statistically significant, and when the regressors are correlated to these effects. In addition, with regard to the lagged variables, OLS return inconsistent estimates as lags and μ_i are correlated, even if the idiosyncratic component of the error term is serially uncorrelated. One way to overcome these problems is the use of an instrumental variables procedure applied to a dynamic model of panel data. In particular, a GMM estimator uses the dynamic properties of the data to generate proper instrumental variables (Arellano and Bond, 1991; Arellano and Bover, 1995). To deal with the fact that measurement errors are likely to be determined not only by random errors but by the specific and persistent characteristics of each country, we use the GMM-system (Arellano and Bover, 1995; Blundell and Bond, 1998) that combines into a single system the regression equation in both differences and level. The GMM-system estimator allows to control for unobserved region-specific effects that are potentially correlated with the explanatory variables.

Since the consistency of the parameters obtained by means of the GMM estimator depends crucially on the validity of the instruments, two specification tests are taken into account: the Sargan test of over-identifying restrictions, which tests the null hypothesis of overall validity of the instruments used; and the test for serial correlation of the error term, which tests the null hypothesis that the differenced error term is first and second order serially correlated. Failing to reject the null hypothesis of no second-order serial correlation implies that the original error term is serially uncorrelated and the moment conditions are correctly specified.

3. Classification and evaluation of variables

In this section, we present the data and their background literature used for the ISA construction (see, among the others, Smith and McDonald, 1998; Von Wirén-Lehr, 2001; Sands et al., 2000) and those used to implement the second step of our empirical analysis.

In order to construct the ISA, we use EUROSTAT data for 28 European countries, corresponding to the European NUTS-1 level, for the years 2005–2014. In particular, our dataset consists of 16 variables, belonging to three pillars: Environmental (En), Economic (Ec) and Social (So) (see Table 1).

3.1. En pillar accounts for five variables

The first one, “Final Energy Consumption in Agriculture/Forestry” is defined as “the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself” (EUROSTAT, 2017). Over the last decades there has been a rapidly growth in final energy consumption in agriculture and forestry, in developed economies but especially in the emerging ones. This produces important consequences both in terms of resources’ exhaustion and of negative impact on the environment and human health (Pérez-Lombard et al., 2008). In this sense, the final energy consumption leads to unsustainable development. After all, the energy consumption depends upon climate changes. Energy demand is, in fact, determined by the regulation of the indoor temperature (Aaheim et al., 2009). The second variable, “Electricity generated from renewable resources” is a very important variable since it implies sustainable development. The two main natural sources for electricity supply are precipitations (hydro power) and wind (wind power). In Europe, the most used renewable source is the hydro power, while the use of wind power is importantly increasing (Aaheim et al., 2009). According to the definition provided by EUROSTAT (2016a), the third variable, “Energy intensity of the economy” represents the ratio between the gross inland consumption of energy and the gross domestic product (GDP) for a given calendar year. It measures the energy consumption of a country and its overall efficiency. While the energy intensity contributes to increase the human welfare through the satisfaction of human needs, it requires considerable greenhouse gas emissions (GHGs) and depletion of natural resources as well (Neves and Leal, 2010). Moreover, the growing energy usage in the last decades has strongly produced negative environmental effects such as climate changes and global warming (Pérez-Lombard et al., 2008). The fourth variable, the “Greenhouse gas emissions (GHGs) from agriculture” allows us to account for the greenhouse gas emissions (GHGs) produced by the agricultural sector, that are generally associated to the management of livestock, rice production, biomass burning and agricultural soils (EUROSTAT, 2016b). In particular, the main sources of GHGs is ruminant animals flatulence that produces methane and oxide emissions. Overall, agricultural activities in the EU-28 generated about 470 million tonnes of CO2 equivalent in 2012, corresponding to about 10% of total greenhouse gas emissions (EUROSTAT, 2016b). This doesn’t contribute to a sustainable development. A good news is that lately agriculture GHGs are significantly

Table 1
List of variables for each pillar and their sign.

Pillar	Sign	DESCRIPTION of the indicator	UNIT	Code
En	−	Final energy consumption in Agriculture/Forestry	1000 tonnes of oil equivalent	En1
En	+	Electricity generated from renewable sources	Percentage of gross electricity consumption	En2
En	−	Energy intensity of the economy	kg of oil equivalent per 1000 EUR	En3
En	−	Greenhouse gas emissions in agriculture	Thousand tonnes	En4
En	−	Supply, transformation and consumption of solid fuels -Gross inland consumption – annual data	Thousand tonnes	En5
Ec	+	Real GDP (per capita)	Euro per capita	Ec1
Ec	+	Employment rate in upper secondary and post-secondary non-tertiary education (levels 3 and 4)	Percentage	Ec2
Ec	+	Employment rate in Tertiary education (levels 5–8)	Percentage	Ec3
Ec	+	Gross domestic expenditure on research and development (R&D)	Percentage of gross domestic product (GDP)	Ec4
Ec	−	Unemployment rate – annual data	Percentage	Ec5
Ec	+	Income from agricultural activity	(2004 = 100)	Ec6
So	+	Adult participation in learning	Percentage	So1
So	−	People at risk of poverty or social exclusion	Percentage of the total population and 1 000 persons	So2
So	−	Gender employment gap	Percentage	So3
So	+	Impact of social transfers (excluding pensions) on poverty reduction	Percentage	So4
So	−	Young people neither in employment nor in education and training by sex	Percentage	So5

Note: We define that a given variable, i.e. the j-th variable, is positive (sign = +) if its increase is associated with an increase in the value of the index. Otherwise, the variable is negative (sign = −) if its increase is associated with a decrease in the value of the ISA.

reducing thanks to more efficient farming practices and to livestock reductions. Finally, the variable "Supply, transformation and consumption of solid fuels" is considered. Solid fuels, relatively to gaseous or liquid fuels, are cheaper and thus readily available (SOLID FUEL ASSOCIATION, 2017). However, they require more destructive methods to be extracted and are considered non-renewable since they take thousands of years to form (IEA, 2017). Moreover, solid fuels negatively affect the human health, following Kliucininkas et al. (2014), Kim et al. (2013), Happo et al. (2013). In particular, these studies highlight that solid fuels have a greater impact than the pollution emitted from traffic. In the light of that, supply, transformation and consumption of solid fuel do not entail sustainability at all.

3.2. Ec pillar accounts for six variables

They are: "Real GDP per capita", "Employment rate in upper secondary and post-secondary non-tertiary education (levels 3 and 4)", "Employment rate in Tertiary education (levels 5–8)", "Gross domestic expenditure on research and development (R&D)", "Unemployment rate – annual data" and "Income from agricultural activity".

Those variables can be classified into two groups of variables. A fist one composed by "pure economic variables" ("*Real GDP per capita*" and "*Income from agricultural activity*") and a second one that includes the "socio-economic" variables (the remaining variables). As regarding the first group, the "*Real GDP per capita*" is one of the most important indicators of an economy's growth level. Introducing the GDP in ISA is crucially important because although it represents a not sufficient condition for sustainability, it does denote a necessary one, being the foundation of the economic growth. Thus, the concept of sustainable development solves the conflict between economic growth and environmental protection (Tampakoudis et al., 2014). Moreover, this concept has evolved over time. As a matter of fact, following the Report of the World Commission on Environment and Development (WCED, 2007), sustainable development is referred to "*development which meets the needs of the present without compromising the ability of future generations to meet their own needs*". Another definition of sustainable development has been provided by the Report of the United Nations Conference on Environment and Development (UNSD, 1992). It concerns "*the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations*". Finally, the European Commission defines sustainable development as "*meeting the needs of present generations without jeopardizing the ability of future generations to meet their own needs – in other words, a better quality of life for everyone, now and for generations to come*" (European Commission, 2016). The "*Income from agricultural activity*" focuses on the agricultural activity. In fact, the agricultural sector faces one major challenge: almost one billion people are hungry every day while the total population will grow more than two billion people by 2050 (Food and Agricultural Organization of the United Nations (FAO), 2013). Therefore, income and productivity from agricultural activities are crucially important for the development of rural livelihoods in all countries (Davis and Winters, 2010). Certainly, in a sustainable perspective, such a development must be implemented via the so-called "*sustainable intensification*" meaning mitigating and adapting to climate changes by also lowering emissions per unit of output (Campbell et al., 2014). The indicator corresponds to the deflated (real) net value added at factor cost of agriculture, per total annual work unit. The implicit price index of the GDP is used as deflator. The "*Gross domestic expenditure on research and development (R&D)*" is a crucial variable in terms of sustainability. In fact, there is a two-way relationship between (R&D) and sustainable growth. Following Akcali and Sismanoglu (2015) innovation entails sustainable growth, employment increase, social welfare and higher quality of life. On the other hand, sustainable growth raises the importance of innovation as well. The group of socio-economic variables, namely, the "*Employment rate in upper secondary and post-secondary non-tertiary education (levels 3 and 4)*", "*Employment rate in Tertiary education (levels 5–8)*" and "*Unemployment rate*", try to face the problem of employment and unemployment. The variables pertaining to the employment are important indicators of sustainability. First of all, it is an economic issue since employment helps to avoid the poverty risk. It is also a social issue because higher income improves health and education. Economies investing in employment enjoy positive development spillovers (ILO, 2014). Importantly, employment implies higher living standards, increases productivity and strengthening of social cohesion (Betcherman, 2015). In this context, the gender employment gap weakens the economy from a sustainability viewpoint. For instance, one of most issued policy targets is the increase of the job participation rates of the lone mothers (Millar and Ridge, 2009). Employment sustainability is crucial to achieve such a target.

3.3. So pillar accounts for five variables

The "*Adult participation in learning*" variable is used since, according to the United Nations and following Venkataraman (2009), education is one of the main pillars of the sustainable development. "*Learning can mean practising, studying or reading about something. It can also mean being taught, instructed or coached. This is so you can develop skills, knowledge, abilities or understanding of something. Learning can also be called education or training. You can do it regularly (each day or month) or you can do it for a short period of time. It can be full time, or part time, done at home, at work, or in another place like a college. Learning does not have to lead to a qualification. We are interested in any learning you have done, whether or not it was finished*" (NIACE, 2015). The "*People at risk of poverty or social exclusion*" variable is here introduced to monitoring the gap between riches and poors.

Nowadays, such gap is increasing both among and within countries. This compromises the sustainable development of an economy (Sustainable Development, 2001; Samuel and Uwizeyimana, 2017). Although the "*Gender employment gap*" variable seems to be related to the economic pillar, it is mainly a social issue. In fact, the Eurofound Report (2016) highlights that, albeit the women's labour market participation has increased over the last years, the gap between men and women participation rates is still there. Moreover, it is documented that "*the total cost of a lower female employment rate is estimated to have been around €370 billion in 2013, corresponding to 2.8% of the EU's GDP*". Therefore, the (negative) consequence in term of sustainability is crucial. Widespread poverty is a growing concern of policy makers. Therefore, poverty alleviation represents a key component of a sustainable development (Sustainable Development, 2001; Samuel and Uwizeyimana, 2017). Thus, it seems reasonable the use of the "Impact of social transfers (excluding pensions) on poverty reduction". In addition, Social transfers represent one of several sustainable development strategies (Sustainable Development, 2001). The last variable, "*Young people neither in employment nor in education and training by sex*" variable refers to the so-called NEET generation, namely young people between 15 and 29 years old, that are neither in employment nor in education and in training. The NEET generation is one of the most important concerns of the policy makers because it heavily compromises the sustainable development of an economy. Following Elder (2015), this generation of people means being at risk of both labour market and social exclusion. Moreover, the NEET rate is a clear sign of the healthy transition from school to work.

Table 1 reports the sign of these variables. For instance, if the "*real GDP*" (Ec pillar) increases we expected that the index (ISA) increases; on the other hand, if the "Unemployment Rate" increases we expected for a reduction in the ISA.

Table 2 shows the average value and standard deviation of the variables used in the first step of analysis. In particular, the countries with the higher value, on average, of the variables with negative sign in the Environmental pillar (En) are: France (4187.89), Poland (3704.99) and Netherland (3615.73) for "*Final energy consumption in Agriculture/ Forestry*" (En1); Bulgaria for "*Energy intensity of the economy*" (En3); France and Germany for "*Greenhouse gas emissions in agriculture*" (En4) and "*Supply, transformation and consumption of solid fuels*" (En5). These variables are associated with a decrease of ISA. On the contrary, Austria (65.80) and Sweden (56.87) have, on average, the higher value in the "*Electricity generated from renewable sources*" (En2) variable, which is associated with an increase of ISA.

Looking at the Economic pillar (Ec), the countries with the higher value, on average, of the variables with positive sign are: Luxembourg (79370.00) for "Real GDP per capita" (Ec1) variable; Sweden and Denmark for "*Employment rate in upper secondary and post-secondary non-tertiary education*" (Ec2) and "*Employment rate in Tertiary education*" (Ec3) variables; Finland and Sweden for "*Gross domestic expenditure on research and development*" (Ec4); Bulgaria and Slovenia for "Income from agricultural activity" (Ec6). These variables are associated with an increase of ISA. Conversely, Spain and Greece are the countries with, on average, the "*higher Unemployment rate*" (Ec5) variable, which is associated with a decrease of ISA.

Regarding the Social pillar (So), Denmark has, on average, the higher value for both "*Adult participation in learning*" (So1) and "*Impact of social transfers (excluding pensions) on poverty reduction*" (So4), which are associated with an increase of ISA (+ sign). On the other hand, the countries with the higher value, on average, of the variables with negative sign in the social pillar are: Bulgaria for both "*People at risk of poverty or social exclusion*" (So2) and "*Young people neither in employment nor in education and training by sex*" (So5) variables; and Malta for "Gender employment gap" (So3).

Several countries could exhibit higher performances in one aspect of sustainability to the detriment of another dimension. Consequently, policy makers would have difficulties to define the path of sustainability of these countries. Thus, we are not able to rank countries a priori. This ambiguity is also motivated by the fact that sustainability is a multidimensional concept involving different aspects simultaneously. Thus, an analysis of a single variable at a time might lead to misleading results.

The summary statistics of variables used in the second step of empirical analysis are reported in Table 3. Climate variables, mean annual temperature (°C) (MAT) and mean annual precipitation (mm) (MAP) are obtained from the Climate Research Unit (CRU) Time-Series (TS) Version 3.22 of the University of East Anglia. Data on agricultural production (proxy by wheat and spelt yield) provided by EUROSTAT for EU-28 for the years 2005–2014. However, our analysis can only consider wheat and spelt yield. This is due to high presence of missing values per country of other crop yields. Our future research agenda would extend this analysis to other agricultural yields, according to future data availability. Table 3 shows that the climatic variables have a high variability. In particular, MAP passes from a minimum of 281 mm of rain to a maximum of 1985 mm of rain. Over the years also wheat and spelt yields (W&S) undergo major variations, ranging from a minimum yield of 0.50 to a maximum yield of 10. ISA is on average 0.45.

4. Results

The results of the first step of analysis provide an overview on how EU-28 countries rank according to the ISA. In particular, in order to make easy-to-read results on *sustainable agriculture performances* of a countries, following Agovino et al. (2017), for each year countries are categorized in three classes: high (H), medium (M) and low (L) according to the level of the ISA index, as follows. We compute the mean (hereafter, m_t, where t denotes the year) and the standard deviation (σ_t) of the ISA index. Then, the countries that exhibit a value between the minimum (that, by construction is 0) and $m_t - 0.5\sigma_t$ are classified as Low. Countries whose values belong in the interval $[m_t - 0.5\sigma_t, m_t + 0.5\sigma_t)$ are defined as Medium and, finally, if the value of the index falls in the interval $[m_t + 0.5\sigma_t, max_t]$, where max_t is the maximum of the ISA in a given year, are classified as High.

The Figs. 1a and 1b show the sustainable agriculture performances of the EU-28 countries. In particular, the Fig. 1a shows three clusters in the year 2005:

(1) cluster with *high performance*, which ranges from 0.3979 to 0.6681. It includes Austria, Denmark, Finland, Ireland, Netherlands, Sweden and United Kingdom;
(2) cluster with *medium performance*, which ranges from 0.2257 to 0.3979. It comprises Belgium, Cyprus, Czech Republic; Estonia; France, Germany, Hungary, Latvia, Lithuania, Luxembourg, Portugal, Spain;
(3) cluster with *low performance*, which ranges from 0 to 0.2257. It includes Croatia, Greece, Italy, Slovakia, Romania.

The *high performances* of the countries in the first cluster are driven by the *high performance* in the three pillars of agricultural sustainability i.e., environmental, economic and social. This is the case of Austria, Denmark, Finland, Sweden. In contrast, the *low performance* of the countries in the third cluster (such as: Croatia, Greece, Italy, Romania) is driven by low performance in the two pillars of agricultural sustainability i.e., economic and social. Their performance in environmental pillar is medium (see Tables A2–A4 in Appendix).

These clusters persist over the years with exceptions for some countries (see Table A1 in the Appendix).

In 2014, as shown by the Fig. 1b, the performance of Cyprus, Germany, Spain (from ISA medium in 2005 to low ISA in 2014) and Ireland (from high ISA to medium ISA) worsen. On the contrary, performance of Luxembourg (from medium to high) and Slovakia (from low to medium) improved. The other countries have the same performance as 2005.

Regarding the second step of our analysis, Table 4 summarizes the causality relationships among the variables presented in Table 3. The Granger test results are listed in Table A5 in Appendix. Table 5 summarizes the results of econometric estimates in terms of sign and significance. The empirical results of the analysis with the coefficients and

Table 2
Summary statistics of variables used in the first step of empirical analysis.

Country	Statistics	En1	En2	En3	En4	En5	Ec1	Ec2	Ec3	Ec4	Ec5	Ec6	So1	So2	So3	So4	So5
Austria	Mean	517.48	65.80	113.32	7032.77	5313.10	35410.00	75.27	84.94	2.68	5.05	100.72	13.61	18.62	10.93	45.88	7.59
	sdv	18.39	2.41	5.15	60.09	755.94	837.20	1.26	0.82	0.24	0.45	13.27	0.50	1.04	1.72	3.35	0.48
Belgium	Mean	791.96	7.33	158.00	10066.36	6045.10	33500.00	68.76	82.25	2.08	7.92	101.42	7.37	21.21	12.45	44.97	11.63
	sdv	71.72	3.84	9.25	144.51	1103.21	487.85	0.70	0.72	0.25	0.53	16.95	0.41	0.62	2.16	1.25	0.85
Bulgaria	Mean	220.57	12.88	501.77	5060.04	32905.40	5060.00	68.10	82.60	0.54	9.67	110.32	1.67	50.78	8.10	20.02	20.94
	sdv	45.75	3.63	59.70	197.61	3043.23	392.94	3.33	1.97	0.11	2.39	21.82	0.21	6.81	1.93	3.11	1.97
Croatia	Mean	210.37	37.58	205.61	2669.76	1125.50	10590.00	61.90	79.58	0.80	12.83	101.09	2.90	32.68	12.71	30.71	15.62
	sdv	7.26	3.48	8.49	189.77	96.28	420.59	3.14	2.41	0.05	3.02	10.29	0.32	1.95	2.33	2.87	2.50
Cyprus	Mean	38.44	2.47	140.92	615.53	26.70	22810.00	71.80	82.44	0.43	8.10	99.97	7.70	25.42	14.64	33.00	13.68
	sdv	1.95	2.74	8.75	31.64	20.70	1410.99	4.19	3.64	0.04	4.55	15.22	0.82	1.48	4.38	5.05	3.76
Czech Republic	Mean	553.95	8.04	288.13	8198.12	52863.30	14870.00	72.67	82.57	1.48	6.55	107.92	8.26	15.72	18.41	49.74	8.78
	sdv	32.93	3.67	19.07	205.27	3795.09	549.64	0.86	1.24	0.28	0.98	13.22	2.10	1.66	0.70	3.69	1.71
Denmark	Mean	687.88	32.67	77.26	10683.65	6319.40	44700.00	78.87	86.40	2.81	5.81	108.15	30.68	17.42	7.27	57.05	5.26
	sdv	28.57	8.19	5.38	177.20	1459.32	933.81	1.66	0.89	0.26	1.60	31.19	1.60	0.64	1.19	1.65	0.99
Estonia	Mean	103.81	7.79	374.01	1179.18	17337.40	12130.00	71.23	82.90	1.50	9.25	109.65	9.96	23.28	5.89	26.37	11.23
	sdv	10.93	5.63	25.06	74.56	2326.53	847.41	3.45	2.75	0.43	3.68	25.46	2.44	1.49	2.30	4.29	1.94
Finland	Mean	736.48	28.23	188.73	6419.18	14039.10	35230.00	72.70	84.39	3.46	7.84	100.76	23.55	17.13	3.58	52.80	8.57
	sdv	19.92	1.86	6.20	62.96	2367.73	1129.65	1.25	0.64	0.19	0.68	10.33	0.96	0.46	1.09	3.18	0.98
France	Mean	4187.89	15.43	131.50	78223.70	18666.90	31020.00	71.06	80.59	2.15	9.11	102.85	8.25	18.79	9.54	45.95	11.65
	sdv	56.98	1.40	6.49	1177.33	2149.04	362.77	1.27	0.89	0.09	0.87	16.76	4.94	0.36	1.22	2.80	0.79
Germany	Mean	2.35	18.45	126.49	63373.25	242229.40	32240.00	74.60	86.20	2.67	7.32	103.55	7.86	19.94	11.06	38.37	8.22
	sdv	4.96	5.64	8.52	1278.46	7998.69	1283.90	2.54	1.61	0.17	2.01	22.31	0.16	0.60	1.17	5.76	1.37
Greece	Mean	770.00	13.26	131.78	8744.96	62121.90	19950.00	58.03	76.72	0.66	15.39	99.69	2.89	30.77	24.35	14.25	15.49
	sdv	357.56	4.77	5.51	88.47	5462.41	2247.33	5.78	5.76	0.09	7.59	7.44	0.53	3.21	4.01	1.38	3.46
Hungary	Mean	504.59	5.79	251.08	6071.27	11128.30	10090.00	64.36	79.51	1.14	9.10	108.98	3.36	31.22	12.85	51.84	13.16
	sdv	54.40	1.29	17.38	244.48	531.77	280.89	1.97	1.55	0.16	1.62	20.64	0.40	1.90	1.27	5.66	1.23
Ireland	Mean	277.12	14.65	86.87	18513.74	6068.20	37970.00	68.00	81.87	1.44	9.97	101.74	7.21	26.52	13.40	54.14	15.34
	sdv	36.31	5.14	5.51	417.49	380.73	1787.20	5.84	2.80	0.16	4.21	15.50	0.34	2.62	4.57	7.54	3.42
Italy	Mean	2774.42	21.93	108.79	31898.24	23330.60	27040.00	67.07	77.17	1.20	8.73	100.62	6.32	26.77	23.26	19.96	18.82
	sdv	145.32	6.30	5.11	977.96	1997.29	1182.54	1.96	1.00	0.10	2.19	10.60	0.64	1.67	2.39	1.28	2.20
Latvia	Mean	137.15	43.42	232.48	2448.84	151.00	9370.00	68.30	84.33	0.60	12.17	106.06	6.52	37.80	5.18	22.08	13.70
	sdv	8.18	3.88	14.61	144.59	24.17	732.19	4.83	2.09	0.07	4.43	14.52	0.87	3.91	3.79	5.00	2.50
Lithuania	Mean	108.39	7.74	263.88	3771.97	430.50	9650.00	65.43	87.04	0.85	10.71	107.26	5.29	32.12	3.47	29.21	10.23
	sdv	4.52	3.55	42.65	48.30	55.74	983.11	3.94	0.94	0.08	4.31	20.38	0.56	3.94	3.45	4.94	1.85
Luxembourg	Mean	25.08	4.11	113.47	653.37	112.60	79370.00	67.11	83.46	1.51	4.98	98.47	11.72	17.33	16.72	44.76	5.69
	sdv	2.15	0.87	10.91	13.73	21.72	2323.81	1.00	0.50	0.16	0.55	20.06	2.93	1.16	2.33	3.46	0.60
Malta	Mean	2.51	0.65	141.22	96.53	0.00	16030.00	76.27	84.83	0.64	6.49	97.30	6.40	21.43	36.91	32.98	10.26
	sdv	2.37	1.03	13.69	7.14	0.00	936.00	1.26	1.66	0.11	0.37	6.41	0.75	1.62	5.33	2.22	0.95
Netherlands	Mean	3615.73	8.52	130.32	18390.75	12850.60	38010.00	78.95	86.85	1.81	5.37	102.73	17.08	15.66	12.61	49.31	4.49
	sdv	192.09	1.66	6.21	254.66	768.25	791.77	1.60	0.72	0.12	1.18	13.81	0.72	0.60	1.40	2.54	0.76
Poland	Mean	3704.99	6.80	277.58	30093.90	135382.00	9210.00	62.10	82.60	0.71	10.54	106.08	4.65	30.97	14.49	29.03	11.45
	Sdv	262.54	3.36	27.59	443.11	3684.59	936.43	1.91	0.88	0.14	2.97	13.70	0.35	6.39	0.58	3.41	1.31
Portugal	Mean	367.29	39.64	139.50	7135.07	4479.50	16660.00	68.60	82.21	1.29	11.75	101.03	7.14	25.70	9.97	27.23	11.86
	Sdv	57.92	8.29	8.08	123.48	781.98	400.50	1.28	2.86	0.25	2.80	12.19	2.73	1.02	2.50	2.20	1.26
Romania	Mean	362.41	31.64	290.85	18371.38	35472.30	6250.00	64.92	83.98	0.46	6.77	102.25	1.61	43.45	14.90	21.87	15.53
	Sdv	93.14	4.49	37.26	1202.34	5009.22	514.30	0.79	1.35	0.06	0.47	27.26	0.19	2.27	1.43	3.78	1.90
Slovakia	Mean	141.81	18.45	269.48	3038.03	7609.70	12230.00	67.72	79.41	0.61	13.24	101.44	3.63	22.02	15.78	37.82	13.45
	Sdv	10.75	2.16	39.37	82.51	653.08	1090.00	1.58	3.68	0.16	1.79	10.64	0.56	3.93	1.08	3.04	1.22
Slovenia	Mean	72.08	31.02	200.40	1730.20	4917.10	17690.00	69.50	85.82	1.99	7.19	110.04	14.55	18.63	8.43	47.30	8.02
	Sdv	3.47	2.18	8.93	51.98	491.37	699.21	2.57	2.12	0.46	1.88	18.94	1.33	1.22	1.12	3.54	1.09
Spain	Mean	2662.98	28.17	124.87	37160.15	27888.80	23230.00	65.16	78.59	1.27	17.18	100.35	10.89	25.66	15.78	24.80	15.95
	Sdv	254.70	6.48	8.27	1269.86	9644.02	872.98	4.87	2.98	0.08	6.86	8.24	0.36	1.83	5.66	5.49	2.70
Sweden	Mean	579.85	56.87	133.85	7091.70	3993.60	39420.00	80.38	86.82	3.33	7.57	104.01	23.48	15.54	5.51	53.60	8.24
	Sdv	156.63	4.14	6.79	181.76	391.49	983.67	1.06	0.60	0.12	0.80	14.95	3.94	0.91	0.53	6.64	1.07
United Kingdom	Mean	891.52	8.42	113.58	44200.95	57697.50	29920.00	77.05	85.03	1.64	6.62	104.56	20.23	23.52	12.23	41.84	12.10
	Sdv	40.76	4.29	9.53	813.81	6849.65	624.18	1.85	1.69	0.04	1.22	9.83	4.07	0.90	1.04	4.32	1.96

the goodness tests are given in Table A6 in the Appendix. In particular, the Sargan test, which allows us to verify the validity of the instruments, does not reject the null hypothesis and this confirms the validity of instruments used. In addition, there is evidence of the presence of serial correlation of first order (we reject the null hypothesis); whereas, there is no evidence of the presence of second-order serial correlation

Table 3
Summary statistics of variables used in empirical analysis.

Variables	Obs	Mean	SD	Min	Max
ISA	280	0.455	0.207	0	0.917
W&S	269	4.965	2.125	0.495	10.012
MAT (°C)	252	9.848	4.123	1	19.4
MAP (mm)	252	802	302.122	281	1985

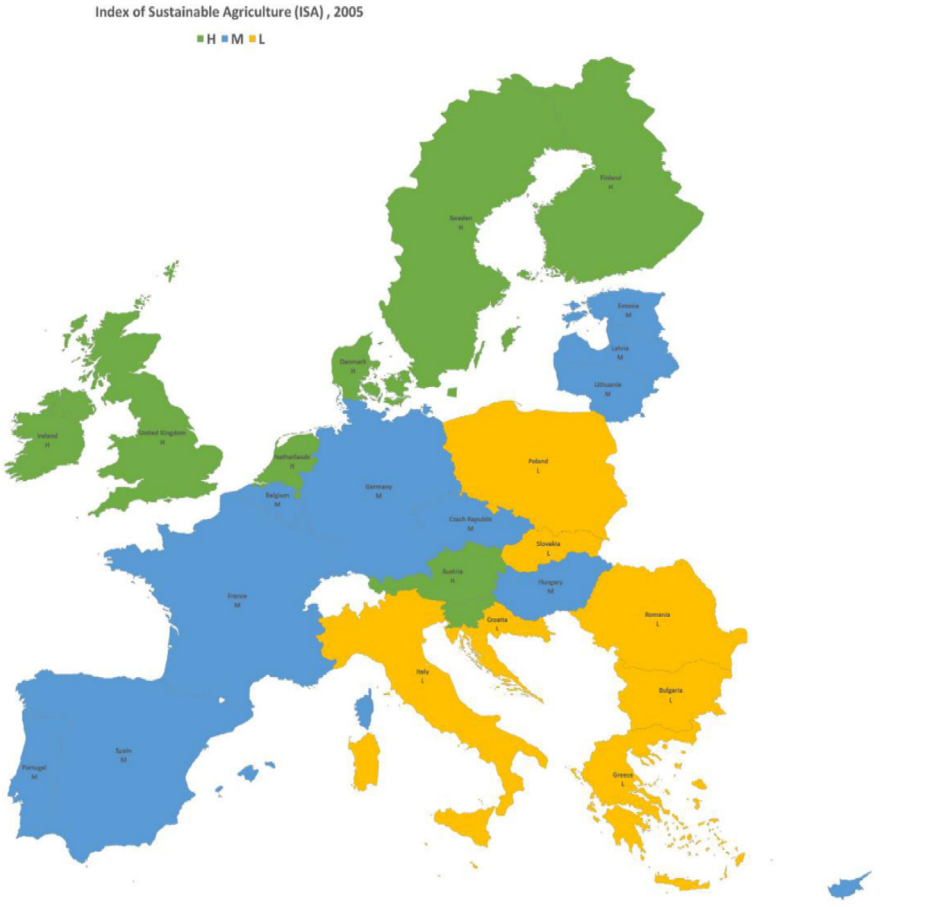
(the null hypothesis is not rejected). The consistency of the GMM estimator requires that there is no serial correlation of the second order in the differenced error term (see Table A4).

In order to make easy-to-read comments, our analysis will focus only on Tables 4 and 5 which qualitatively synthesize the causal relationship and the sign of the relationship among ISA, climate change and agricultural production. The empirical results allow us to conclude as follows:

- W&S are Granger-caused by MAT and MAP (Table 4). The regression analysis shows that wheat and spelt yields are negatively influenced by an increase in temperature and by the amount of rainfall (Table 4). On the contrary, W&S is not Granger-caused by ISA, and this is confirmed by empirical analysis. In fact, the coefficients associated to the lags of ISA are not significant (Table 4).
- The ISA is Granger-caused and negatively affected by W&S. In addition, climate change Granger-cause the ISA; in particular, an increase in temperature (MAT) negatively affects sustainable agriculture.
- MAT (mean annual temperature) is Granger-caused by the ISA (Table 4). More sustainable agriculture has the effect of reducing the average annual temperature. In other words the earth's heating and hence the likelihood of desertification in some areas of the countries studied decreases (Table 4).
- MAP (mean annual precipitation) is Granger-caused both wheat and spelt yields and mean annual temperature. In particular, MAP is negatively affected by both variables.

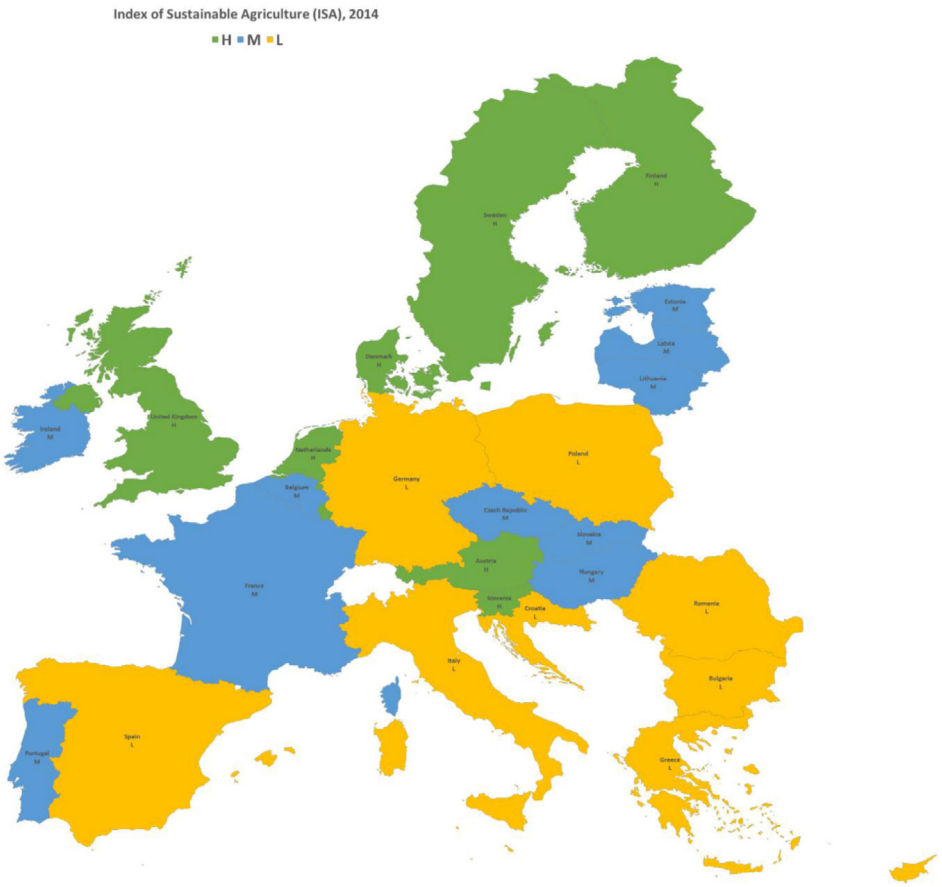
5. Discussion

The discussions derived from this paper are both methodological and political. Importantly, they can be divided according to the two steps developed in our analysis.



Source: Our elaboration on Eurostat data.
Note: the box maps show the distribution of ISA among EU-28 countries considering three classes i.e., high (H), medium (M) and low (L) according to the level of the ISA index for the years 2005. Ranges ISA 2005: Low [0, 0.225718]; Medium [0.225718, 0.397918]; High [0.397918, 0.6681].

Fig. 1a. Box maps of the Index of Sustainable Agriculture (ISA), 2005. *Source:* Our elaboration on Eurostat data. Note: the box maps show the distribution of ISA among EU-28 countries considering three classes i.e., high (H), medium (M) and low (L) according to the level of the ISA index for the years 2005. Ranges ISA 2005: Low [0, 0.225718]; Medium [0.225718, 0.397918]; High [0.397918, 0.6681].



Source: Our elaboration on Eurostat data.
Note: the box maps show the distribution of ISA among EU-28 countries considering three classes: high (H), medium (M) and low (L) according to the level of the ISA index for the years 2014. Ranges ISA 2015: Low [0, 0.197543964]; Medium [0.197543964, 0.340634608]; High [0.340634608, 0.5792].

Fig. 1b. Box maps of the Index of Sustainable Agriculture (ISA), 2014. *Source:* Our elaboration on Eurostat data. Note: the box maps show the distribution of ISA among EU-28 countries considering three classes: high (H), medium (M) and low (L) according to the level of the ISA index for the years 2014. Ranges ISA 2015: Low [0, 0.197543964]; Medium [0.197543964, 0.340634608]; High [0.340634608, 0.5792].

Table 4
Summary of Granger-causality test.

X variables	*X Granger Causes Y*	Y variables			
		Wheat & Spelt	Sustainability Index	MAT	MAP
	Wheat & Spelt	–	Yes	Not	Yes
	Sustainability Index	Not	–	Yes	Not
	MAT	Yes	yes	–	Yes
	MAP	Yes	not	Not	–

5.1. First step: the ISA

As regarding the methodological/empirical discussions, the first worth mentioning relates to the *utility of the construction of a composite indicator of sustainability in agriculture*. This method has allowed us to cope with multidimensional set of indicators to be aggregated into a unique composite indicator that can improve our understanding of the complex concepts such as supporting the sustainable agricultural development and environmental protection. Thus, in the first step, our study examines the construction of the overall ISA to understand which countries are closer in terms of performances and are at the nexus for sustainable agriculture and environment. Moreover, the index enables us to make suggestion for policy makers and civil society to better understand current conditions and compare performance among the 28 European countries[3]. This Index has, in fact, the advantage of both improving public awareness (mass media and society in general) by comparing various geographical levels (different agricultural systems) and improving initiatives for the promotion of agricultural practices and technologies that are environmentally sustainable. The results allow us to conclude that there is a first group of countries (Austria, Denmark, Finland, Ireland, Netherlands, Sweden and United Kingdom) featuring high performances in sustainable agriculture. This can be seen as a strong commitment driven by forces that determine the prospects of the agricultural sector dominated by international and European developments related to the demand for and supply of production to the sustainable agriculture. These countries with the highest performance are in prime agricultural countries that are already facing some of the strongest environmental pressures (Zalidis et al., 2004). Their prevailing natural

[3] Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, United Kingdom, Austria, Finland, Sweden, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania and Croatia.

Table 5
Summary of the empirical results.

X variables	*X Granger Causes Y*	*Y variables*											
		Wheat & Spelt			Sustainability Index			MAT			MAP		
		lag 1	lag 2	lag 3	lag 1	lag 2	lag 3	lag 1	lag 2	lag 3	lag 1	lag 2	lag 3
	Wheat & Spelt				$-^{***}$	$-^{***}$	$-^{***}$	−	−	+	$-^{*}$	$-^{***}$	$-^{***}$
	Sustainability Index	−	−	+				$-^{***}$	$-^{***}$	$-^{***}$	−	−	−
	MAT	$-^{**}$	$-^{**}$	−	+	$-^{***}$	$-^{**}$				$-^{***}$	$-^{**}$	$-^{***}$
	MAP	$-^{***}$	−	$-^{**}$	−	−	−	+	−	+			

***, **, *: 1%, 5%, 10%, respectively; +, −: positive and negative relationship, respectively.

conditions with a fair rainfall relatively fertile soils in a flat landscape, favor a varied and productive agriculture. Moreover, this factor, together with governmental policies supporting their competitive agricultural sector, good entrepreneurial skills, the state-of-the-art agricultural research, innovative supply and processing industries, the availability of inexpensive natural gas supporting greenhouse horticulture and the enlargement of the European Union with the associated market enlargement, has resulted in the creation of a very strong agricultural sector in these countries. There is clear evidence that agricultural productivity growth responds to research and development efforts. The importance of strengthening the public sector research for agricultural development has been well recognized. It is also now well acknowledged that the target of agricultural R&D has to embrace the twofold goal of agricultural productivity and the environmental performance which accompanies agricultural production. Moreover, in this countries the national initiatives reported by the European Commission, the political instruments assessed most frequently are agri-environment schemes (AES), and they are generally evaluated in terms of the environmental dimension (Prager, 2015). As part of the common agricultural policy (CAP), AES are voluntary schemes (usually of five or ten years' duration) that are designed by EU Member States to promote environmentally friendly agricultural production methods. On the other hand, there is a second group including Belgium, Cyprus, Czech Republic; Estonia; France, Germany, Hungary, Latvia, Lithuania, Luxembourg, Portugal; Spain. Concerning these latter, medium performance effects on agricultural sustainability can be seen as a direct consequence of the two accession wave in 2004 and 2007, the EU15[4] becomes EU27[5], composed of more than 500 million citizens, with a farming population that doubled after the enlargements. While organic land has expanded rapidly in the six "new" countries (Cyprus, Czech Republic, Estonia Hungary, Latvia and Lithuania that joined European Union in 2004) consumption levels have remained at a very medium level in "old" countries (Belgium, France, Germany, Luxembourg, Portugal and Spain). Sustainable agriculture is the key factor for long-term and inclusive growth, especially in "new" countries, due to its strong multiplier impact on other sectors but it goes beyond being a purely environmental issue and includes economic viability as well as social acceptability. European agriculture, particularly in Central Europe is coping more and more not only with economic constraints but with constraints related to changing in the economic and social systems. In fact, specific policies and pressures have been designed to increase competitiveness and profitability on domestic and European market. The need to assure the long term viability and preservation of natural resources has arosen in order to comply with the new emerging requirements concerning access to resources. By doing so, household food security is sustained. The speed of this access to resources has depended not only upon the implementation of national structural policies, but also on the development of support institutions as well as on farmers' willingness and ability to manage new responsibilities (Petersen and Feehan, 2003). Thus, candidate countries were expected to join the EU with different production and export structures and, as a result, on different technological levels (as the already existing member states reveal striking differences in this respect). Finally, there is a third group of countries including Croatia, Greece, Italy, Slovakia, Romania. Their small performances are related to too strict and huge investment that are unaffordable to the countries pushing out of the market realities linked to small producers (Gatzweiler and Hagedorn, 2002). Governments in the Balkans try to harmonize their local legislation with EU rules too literally, often missing opportunities to take advantage of their existing mechanisms that offer flexibility. Another reason lies with the very producers – many of them prefer to operate in the grey economy, where they can continue to operate without any rules and without taking any responsibility. One of the problems facing these Balkan counties, Italy and Greece can be seen in its ageing population. While Europe is taking measures to deal with this problem by providing incentives for younger people willing to join the sector, there is no comprehensive regional policy to further that goal. Another problem has to do with the lack of properly educated and trained agricultural professionals. Education is a mandatory pre-condition for modern and traditional agriculture, therefore those working in the sector need to be educated and trained, including on how to market and sell their products. Thus, supporting sustainable agricultural development involve the ensuring of productive capacity for the future and the increasing productivity (Uthes et al., 2011). However, without consistent policy signals, it is difficult to create a sustainable, productive and resilient agriculture sector. Sustainability agricultural actions often face with conflicting policy signals. At the EU level in fact, some policies often encourage production, while other measures try to offset these negative effects to the detriment also of technical and research efficiency (European Commission, 2017). National governments need to identify these inconsistencies and develop a new set of incentives for achieving sustainable productivity growth with mitigation and adaptation as part of this effort.

5.2. Second step: causal relationships

In the second step we examine the direction of causality between wheat and spelt yields, climate change and ISA using the Granger-causality test. The specific causal mechanisms underlying the relation among these variables are important in order to promote adaptation strategies as well as sustainable, productive and resilient agriculture sector in Europe. In particular, the results allow us to conclude as follows: (i) there is a bidirectional and negative relationship between wheat and spelt yields and mean annual precipitation. This result confirms HP1 and HP2. Mean annual temperature has negative effects on W&S and mean annual precipitation but not vice versa (unidirectional relationship). This result confirms only HP1. In fact, too much rain could rot the crop, and too much sun could be associated with periods of drought that would ruin the crop (Porter and Gawith, 1999; Nelson et al., 2009; Ciscar et al., 2011; Maleksaeidi and Karami, 2012; Ignaciuk and Mason-D'Croz, 2014; Gliessman, 2015). Although rises in temperature can have both positive and negative effects on crop yields (see Section 1), in general, rises in temperature have been found to reduce yields and quality of many crops, as cereal and feed grains (Smith et al. 1996; Adams et al. 1998). Furthermore, an increase in frequency of

[4] Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

[5] EU15 defined in Note 7 + Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria and Romania.

unusually hot nights is found to be damaging to most crops and particularly observed for rice yields (Welch et al., 2010; Wassmann et al., 2009). (ii) The ISA and MAT are characterized by a bidirectional negative relationship. This result confirms HP3 and this can be attributed to an inefficient use of mitigation factors (and in particular agricultural practices) to the climate variability, such as: fertilizers and pesticides, irrigation water etc. Climate change associated with the pollution and use of pesticides in agriculture has devastating effects on the environment and its sustainability (Hall et al., 1996; Delmas et al., 1997). As a result, there is the need for the EU-28 countries to improve climate change adaptation strategies into their agricultural policies in order to reduce unsustainable agricultural practices. A possible strategy is to focus on improving the soil's carbon and water storage capacity, and conserving water in natural systems to alleviate the effect of droughts and to prevent floods, soil erosion and desertification (e.g. through Green Infrastructure[6]). In addition, Agri-Climate-Environmental (Aca) payments should continue to play an important role in introducing or maintaining agricultural practices that contribute to mitigating climate change or favoring adaptation to climate change. These agricultural practices must be compatible with the protection and improvement of the environment, the landscape and its characteristics, natural resources, soil and genetic diversity. (iii) The ISA is negatively affected by W&S and not vice versa (unidirectional causal relationship). This allows us to affirm an important result, i.e. agricultural sustainability does not affect agricultural yield. This result confirms HP4 and allows us to conclude that, given the negative sign of the relationship between the ISA and W&S, wheat and spelt yields can be understood as a proxy for intensive agriculture (conventional-productive system) which makes extensive use of pesticides and pollutants that adversely affect the environment and rural landscape. In fact, in the half-century the general trend was the intensification and industrialization of crop systems in order to increase crop yields (especially with regard to wheat, maize and rice). This mainly led to intensive monoculture and the high application of fertilizers and pesticides as well as irrigation water, agricultural machinery (Victor and Reuben 2002; Lin, 2011; Tilman et al., 2002; Pretty et al. 2003; Goulding et al. 2008, Pretty, 2008). The relationship between intensive cultivation and chemical pesticides is particularly strong (Pretty, 2008). This conventional system has led, on the one hand, to increase productivity and, on the other hand, to intensive and often irreversible exploitation of natural resources, i.e., soil erosion, water contamination, hydrogeological pollution, deforestation, loss of biodiversity. For this reason, in the last decade, the growth trend of agricultural productivity has been significantly reduced to a phase of "stagnation of yields". On the contrary, sustainable agricultural production is dependent on effective management of a range of interdependent physical and natural resources (for instance, land, water, energy, capital etc…) (Mcintyre et al., 2009). Thus, as concern the future of agriculture, a range of adjustment measures for sustainability must be undertaken relating to farming practices, for example planting, harvesting and watering/fertilising existing crops, using different varieties, diversifying crops, implementing management practices. The Common Agricultural Policy (CAP) offers a number of instruments to find adequate answers to the challenges of climate change, a more sustainable EU agriculture The focus of the rural development policy on sustainability is clearly visible by the fact that at least 30% of the budget of each European rural development programme has been reserved for voluntary, targeted measures that are beneficial for the environment and climate change (European Commission, 2012). The European Union is moving towards this sustainable path. At the core of EU Development Policy is the investment in sustainable agriculture and the development of supportive policies. Making agriculture resilient, step by step, so that scarce resources can be managed more effectively has a pivotal place in both internal and external policies. This is based on the belief that an economically and socially sustainable agriculture can make a vital contribution in our response to the most urgent climate change, also thanks to innovation. Opening the door to the approaches of innovation (e.g. technological solutions to adjustments in farm management or structures, and to political changes, such as adaptation plans), mitigation (with its potential to reduce climate change impacts) and adaptation actions (e.g. by developing resilience to shock and disasters, such as flooding, drought and fire) and a growth in sustainable productivity could in fact, ensure the economic viability that can help to make farming cleaner, less exposed to volatility in the prices of inputs and more resistant to disasters. Importantly, this may contribute to the development of societies that are more resilient to the threat of climate change. Resilience is defined as the propensity of a system to retain its organizational structure and productivity following a perturbation (Vandermeeret al., 1998). Thus, in agriculture crop diversification may provide the link between stress and resilience because a diversity of organisms is required for ecosystems to function and provide services.

6. Conclusions

This paper contributes to the existing literature providing a wide overview on how European countries rank according to the ISA and its three pillars, i.e. environmental, economic and social. Moreover, important causality relationships among the ISA, climate changes and agricultural production are identified. In particular, we verify that: 1) there is a negative bidirectional relationship between climate change and agricultural yields; 2) there is a negative bidirectional causal relationship between climate change and sustainable agriculture; 3) conventional agriculture negatively affects sustainable agriculture.

Our results allow to draw some important conclusions. First of all, it should be noted that targeted policy reforms must be set across European Countries to strengthen productivity with sustainability without surrendering environmental constraints that will further affect the production risks faced by the agricultural sector (OECD, 2016b). Policy actions should be implemented at different levels:

1) Socio Economic level: The agriculture sector underpins normally a wide range of sector-specific influences, including innovation, macroeconomic, trade, investment, infrastructure, and education and training policies. A greater informative level of agricultural stakeholders, the strengthening production of environmental statistics, could have a significant effect on how these can be able to absorb innovative and resource efficient practices, raise rural incomes, such as agro-ecological approaches.
2) Environmental level: policies in agriculture should be consistent. Policies that promote intensification and the jeopardizing of natural resources must be reformed. Thus, targeted investments in research and development on sustainable productivity are required. It is essential to develop a portfolio of strategies that includes adaptation, mitigation, and technological development MS will have to adopt further mitigation measures specifically focused on the agricultural sector in order to fulfill their global climate commitments. There has been insufficient progress in targeting sustainable agriculture or climate change goals and because such measures remain marginal in expenditure and policy developments have been going in the wrong direction. For instance, over-subsidized insurance might incentivize farmers to maintain practices or crops that are poorly adapted to a changing climate. Market price support which creates incentives for intensification is increasingly used to protect the agriculture sector (OECD, 2012).
3) Economic level: Incentives should focus on sustainability outcomes, as opposed to practices. Agricultural practices are frequently under constraints or promotions (i.e. such as imposed limits on the quantity of nitrogen used) by policies that must incorporate environmental objectives. These practices are often costly and limit the adaptability or flexibility of farmers. Redirecting policies to focus on climate change related outcomes – such as pest control techniques

[6] "Green Infrastructure is the interconnected network of natural areas including some agricultural land, such as greenways, wetlands, parks, forest preserves and native plant communities, and marine areas that naturally regulate storm flows, temperatures, flooding risk, and water, air and ecosystem quality." (p. 1 EC, 2012).

on yields and emission proxies – would enable farmers to weigh trade-offs and adopt more efficient and effective tools to promote and achieve agricultural sustainability, environmental protection sustainable and productivity growth.

By concluding, achieving the goal of sustainable agriculture requires responsible actions by all participants in an economic system. Everyone, including farmers, laborers, policymakers, researchers, retailers, and consumers, plays a key role in determining an agricultural system aiming to meet the needs of the present without compromising the needs of future generations. Nowadays technical solutions exist but they are not sufficient. As a matter of fact, a sustainable, productive and resilient agricultural system needs consistent and multilateral policy actions by the European Countries.

Acknowledgements

We would to express our sincere thanks to the Guest Editor, Professor Bin Chen, and the anonymous Referees for their valuable recommendations and suggestions.

Appendix A

Table A1
Index of Sustainable Agriculture (ISA) of EU-28, 2005–2014.

Country	ISA_2005	ISA_2006	ISA_2007	ISA_2008	ISA_2009	ISA_2010	ISA_2011	ISA_2012	ISA_2013	ISA_2014
Austria	0.5663	0.6067	0.1046	0.468	0.5009	0.4993	0.5605	0.563	0.5719	0.5532
Belgium	0.3627	0.3916	0.0921	0.2312	0.3236	0.3372	0.3344	0.4238	0.3823	0.4009
Bulgaria	0	0	0.069	0	0	0	0.0038	0.0509	0.0988	0.1082
Croatia	0.1944	0.2143	0.0613	0.1389	0.1951	0.1328	0.1479	0.1717	0.2228	0.1921
Cyprus	0.2652	0.2884	0	0.2253	0.2854	0.2156	0.2086	0.2905	0.2511	0.2348
Czech Republic	0.3159	0.3245	0.0793	0.2359	0.2426	0.2417	0.3246	0.3284	0.3689	0.3795
Denmark	0.6554	0.6828	0.0602	0.4391	0.6362	0.6397	0.6351	0.7156	0.5548	0.7124
Estonia	0.2728	0.3128	0.0435	0.1649	0.1561	0.1851	0.2633	0.3258	0.2894	0.2682
Finland	0.6014	0.5614	0.1234	0.4423	0.5248	0.4735	0.4946	0.563	0.5938	0.5116
France	0.2416	0.2515	0.1396	0.1239	0.1848	0.2211	0.2248	0.2589	0.3006	0.3384
Germany	0.229	0.2706	0.2132	0.1776	0.213	0.2168	0.2836	0.251	0.3407	0.206
Greece	0.1467	0.1588	0.0597	0.0484	0.1193	0.0558	0	0	0	0
Hungary	0.2714	0.2532	0.0374	0.0994	0.0949	0.1498	0.2066	0.2029	0.2633	0.272
Ireland	0.4351	0.362	0.095	0.2394	0.2264	0.2346	0.286	0.2981	0.3914	0.3877
Italy	0.1784	0.1804	0.0883	0.0585	0.1227	0.088	0.1577	0.1936	0.2333	0.1733
Latvia	0.2908	0.3353	0.0635	0.154	0.0928	0.1113	0.1698	0.2738	0.284	0.3057
Lithuania	0.2599	0.2469	0.0138	0.1503	0.1366	0.1196	0.2155	0.2763	0.2792	0.2804
Luxembourg	0.3852	0.4424	0.025	0.302	0.3434	0.3865	0.4097	0.4621	0.4543	0.522
Malta	0.2032	0.1916	0.0296	0.1105	0.1757	0.116	0.1497	0.2088	0.2461	0.2443
Netherlands	0.4591	0.4966	0.0668	0.35	0.3989	0.3767	0.3759	0.4485	0.4965	0.4356
Poland	0.0056	0.055	0.155	0.0134	0.0959	0.092	0.1065	0.1317	0.1705	0.151
Portugal	0.3076	0.3238	0.0417	0.2306	0.2968	0.2953	0.293	0.3499	0.3739	0.3606
Romania	0.0847	0.1886	0.0395	0.0958	0.0976	0.103	0.139	0.103	0.1903	0.161
Slovakia	0.1963	0.1925	0.0722	0.1175	0.168	0.1427	0.1865	0.1849	0.2626	0.2847
Slovenia	0.4632	0.5087	0.0436	0.3995	0.4086	0.4467	0.4463	0.4652	0.4508	0.4547
Spain	0.2332	0.2594	0.1716	0.0834	0.1352	0.1342	0.154	0.1795	0.2229	0.1994
Sweden	0.6681	0.6713	0.1285	0.5211	0.5742	0.5963	0.6187	0.6542	0.6514	0.708
United Kingdom	0.4377	0.4336	0.1622	0.3189	0.363	0.291	0.3678	0.3727	0.4497	0.4194
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
max	0.668	0.683	0.213	0.521	0.636	0.640	0.635	0.716	0.651	0.712
mean	0.312	0.329	0.081	0.212	0.254	0.247	0.277	0.312	0.336	0.331
sdv	0.172	0.169	0.051	0.142	0.160	0.164	0.163	0.172	0.150	0.167
mean-0.5sdv	0.226	0.244	0.056	0.141	0.174	0.165	0.196	0.226	0.260	0.248
mean+0.5sdv	0.398	0.413	0.107	0.283	0.334	0.328	0.359	0.399	0.411	0.414

ranges	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*To*	*from*	*to*	*from*	*to*	*from*	*to*
L	0.000	0.226	0.000	0.244	0.000	0.056	0.000	0.141	0.000	0.174	0.000	0.165	0.000	0.196	0.000	0.226	0.000	0.260	0.000	0.248
M	0.226	0.398	0.244	0.413	0.056	0.107	0.141	0.283	0.174	0.334	0.165	0.328	0.196	0.359	0.226	0.399	0.260	0.411	0.248	0.414
H	0.398	0.668	0.413	0.683	0.107	0.213	0.283	0.521	0.334	0.636	0.328	0.640	0.359	0.635	0.399	0.716	0.411	0.651	0.414	0.712

Note: high (H) ISA in the green cells; medium (M) ISA in the blue cells; and low (L) ISA in the yellow cells.

Table A2
Index of Economic pillar (Ec) of EU-28, 2005–2014.

Country	Ec_2005	Ec_2006	Ec_2007	Ec_2008	Ec_2009	Ec_2010	Ec_2011	Ec_2012	Ec_2013	Ec_2014
Austria	0.6633	0.5293	0.3937	0.3927	0.4506	0.4197	0.5907	0.5763	0.5787	0.5534
Belgium	0.5135	0.3985	0.3528	0.1877	0.3628	0.3443	0.395	0.578	0.467	0.4859
Bulgaria	0	0.1153	0.1412	0.1912	0.1395	0.0784	0.1964	0.2736	0.3465	0.3244
Croatia	0.273	0.092	0.1693	0.0638	0.156	0.0068	0.1098	0.1314	0.232	0.1821
Cyprus	0.2654	0.2544	0.173	0.2185	0.325	0.1577	0.2083	0.3704	0.3078	0.2488
Czech Republic	0.4698	0.3034	0.2534	0.2134	0.2397	0.2008	0.3976	0.4076	0.4853	0.5185
Denmark	0.9253	0.6484	0.3581	0.2976	0.6438	0.5932	0.6314	0.7674	0.4843	0.7403
Estonia	0.4323	0.3009	0.3018	0.1461	0.1433	0.1231	0.3345	0.4374	0.4155	0.3882
Finland	0.8575	0.4614	0.4774	0.3441	0.5157	0.3663	0.459	0.5727	0.609	0.4935
France	0.5357	0.3225	0.3379	0.1808	0.3181	0.356	0.4289	0.4957	0.4718	0.5581
Germany	0.5545	0.4043	0.5068	0.3417	0.4075	0.3794	0.6264	0.5085	0.7642	0.3742
Greece	0.1619	0.1343	0.1641	0.0378	0.167	0.0127	0	0	0	0
Hungary	0.4499	0.1942	0.123	0.0093	0	0.0489	0.2402	0.2505	0.3896	0.3946
Ireland	0.4637	0.3244	0.3418	0.2603	0.2254	0.1778	0.3283	0.3374	0.4817	0.4868
Italy	0.2407	0.195	0.1245	0.0899	0.1862	0.0781	0.3198	0.3687	0.4459	0.3017
Latvia	0.3523	0.3064	0.2026	0.0887	0.0362	0	0.1501	0.3037	0.3108	0.363
Lithuania	0.3646	0.1875	0.2387	0.1211	0.0953	0.0115	0.2245	0.3321	0.326	0.3157
Luxembourg	0.5338	0.4726	0.3771	0.2836	0.3336	0.3901	0.4904	0.5922	0.5499	0.7169
Malta	0.1688	0.2231	0.1993	0.1589	0.2845	0.1249	0.2789	0.3791	0.4459	0.4252
Netherlands	0.7131	0.5761	0.305	0.3724	0.4873	0.4191	0.4634	0.6201	0.6967	0.5708
Poland	0.3153	0	0.1634	0	0.1627	0.1196	0.2345	0.2615	0.3641	0.2847
Portugal	0.3909	0.2293	0.2108	0.1557	0.2598	0.2108	0.2366	0.3322	0.4002	0.3678
Romania	0.2201	0.1586	0	0.1201	0.1089	0.1114	0.2488	0.1745	0.3593	0.3312
Slovakia	0.3721	0.0761	0.2266	0.0085	0.1113	0.029	0.1814	0.1729	0.3091	0.3367
Slovenia	0.7154	0.4087	0.2465	0.3038	0.3128	0.3463	0.4277	0.4725	0.4589	0.4736
Spain	0.3459	0.2458	0.3186	0.009	0.0924	0.0287	0.1191	0.1642	0.2327	0.2111
Sweden	0.7594	0.6068	0.5325	0.3981	0.501	0.4833	0.581	0.629	0.6221	0.7107
United Kingdom	0.6815	0.4426	0.3417	0.3944	0.4373	0.2464	0.4783	0.4792	0.6036	0.5309
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
max	0.925	0.648	0.533	0.398	0.644	0.593	0.631	0.767	0.764	0.740
mean	0.455	0.308	0.271	0.192	0.268	0.209	0.335	0.392	0.434	0.417
sdv	0.219	0.166	0.122	0.127	0.160	0.167	0.164	0.176	0.154	0.164
mean-0.5sdv	0.346	0.225	0.210	0.129	0.188	0.126	0.253	0.304	0.357	0.335
mean+0.5sdv	0.564	0.390	0.332	0.256	0.348	0.293	0.417	0.481	0.511	0.500

ranges	*from*	*to*	*from*	*to*	*From*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*To*	*from*	*to*	*from*	*to*	*from*	*to*
L	0.000	0.346	0.000	0.225	0.000	0.210	0.000	0.129	0.000	0.188	0.000	0.126	0.000	0.253	0.000	0.304	0.000	0.357	0.000	0.335
M	0.346	0.564	0.225	0.390	0.210	0.332	0.129	0.256	0.188	0.348	0.126	0.293	0.253	0.417	0.304	0.481	0.357	0.511	0.335	0.500
H	0.564	0.925	0.390	0.648	0.332	0.533	0.256	0.398	0.348	0.644	0.293	0.593	0.417	0.631	0.481	0.767	0.511	0.764	0.500	0.740

Note: high (H) Ec index in the green cells; medium (M) Ec index in the blue cells; and low (L) Ec index in the yellow cells.

Table A3
Index of Environmental pillar (En) of EU-28, 2005–2014.

Country	En_2005	En_2006	En_2007	En_2008	En_2009	En_2010	En_2011	En_2012	En_2013	En_2014
Austria	0.9126	0.9058	0.1209	0.8946	0.9	0.9046	0.9021	0.9049	0.906	0.9062
Belgium	0.4206	0.4123	0.0767	0.4003	0.411	0.4251	0.4471	0.461	0.4735	0.4827
Bulgaria	0.1459	0.128	0.1904	0.134	0.1727	0.1968	0.1494	0.1587	0.2203	0.1825
Croatia	0.6984	0.6882	0.1241	0.645	0.6378	0.668	0.6607	0.663	0.687	0.7045
Cyprus	0.4172	0.4034	0.0072	0.381	0.3814	0.3949	0.4136	0.4202	0.4489	0.4509
Czech Republic	0.3434	0.3338	0.1791	0.3224	0.3234	0.3341	0.3646	0.357	0.3636	0.3796
Denmark	0.6383	0.6184	0.0872	0.6095	0.6209	0.6715	0.6984	0.7223	0.7612	0.7947
Estonia	0.3165	0.3287	0.1039	0.2635	0.2569	0.2469	0.2809	0.2984	0.2302	0.2468
Finland	0.6345	0.6088	0.1474	0.5908	0.5757	0.5838	0.6014	0.5949	0.6075	0.5968
France	0.0984	0.0719	0.2523	0.0551	0.0424	0.053	0.0473	0.0531	0.0524	0.0427
Germany	0	0	0.3073	0	0	0	0	0	0	0
Greece	0.4358	0.4337	0.1435	0.4166	0.4225	0.4532	0.463	0.4799	0.5388	0.5382
Hungary	0.4014	0.3824	0.1065	0.3657	0.3697	0.377	0.374	0.3652	0.3835	0.3879
Ireland	0.469	0.4704	0.0608	0.4712	0.4851	0.5028	0.5291	0.544	0.56	0.5727
Italy	0.3958	0.3682	0.1991	0.3652	0.3685	0.3995	0.4108	0.4378	0.4732	0.4756
Latvia	0.7229	0.7084	0.1298	0.664	0.6375	0.6386	0.6788	0.6652	0.6928	0.6992
Lithuania	0.37	0.371	0.0883	0.3437	0.3223	0.3985	0.4115	0.417	0.4557	0.4593
Luxembourg	0.4498	0.4376	0	0.419	0.4208	0.4227	0.4265	0.4241	0.4426	0.4468
Malta	0.4142	0.403	0.0069	0.3786	0.3793	0.3819	0.3868	0.3821	0.4042	0.4194
Netherlands	0.3032	0.3038	0.1427	0.2827	0.2815	0.2572	0.2836	0.2778	0.2827	0.2926
Poland	0.0693	0.0694	0.3732	0.0692	0.0741	0.075	0.0743	0.0994	0.1006	0.1182
Portugal	0.6614	0.6688	0.1129	0.6818	0.6977	0.7461	0.7831	0.7933	0.8008	0.8096
Romania	0.484	0.4806	0.2503	0.4728	0.4903	0.5068	0.4919	0.5026	0.563	0.5872
Slovakia	0.4429	0.4534	0.1221	0.4534	0.4542	0.4652	0.4819	0.4857	0.4899	0.5141
Slovenia	0.6464	0.6355	0.1047	0.615	0.6312	0.6343	0.6183	0.6139	0.627	0.6337
Spain	0.3774	0.377	0.2584	0.4014	0.4381	0.4686	0.4597	0.4503	0.4646	0.4598
Sweden	0.8395	0.8383	0.1403	0.8232	0.8397	0.8437	0.8688	0.8664	0.881	0.8801
United Kingdom	0.3187	0.308	0.184	0.3107	0.3191	0.3229	0.3344	0.3335	0.3629	0.3956
min	0	0	0	0	0	0	0	0	0	0
max	0.9126	0.9058	0.3732	0.8946	0.9	0.9046	0.9021	0.9049	0.906	0.9062
mean	0.443839	0.436029	0.143571	0.422514	0.426921	0.441882	0.4515	0.456132	0.474068	0.481336
sdv	0.216057	0.21602	0.085882	0.213052	0.213809	0.217989	0.223404	0.222162	0.226596	0.229316
mean-0.5sdv	0.335811	0.328019	0.10063	0.315988	0.320017	0.332888	0.339798	0.345051	0.36077	0.366678
mean+0.5sdv	*0.551868*	0.544038	0.186513	0.52904	0.533826	0.550877	0.563202	0.567213	0.587366	0.595994

ranges	*from*	*to*	*from*	*to*	*From*	*to*	*from*	*To*	*from*	*to*	*from*	*to*	*from*	*To*	*from*	*to*	*from*	*to*	*from*	*to*
L	0.000	0.336	0.000	0.328	0.000	0.101	0.000	0.316	0.000	0.320	0.000	0.333	0.000	0.340	0.000	0.345	0.000	0.361	0.000	0.367
M	0.336	0.552	0.328	0.544	0.101	0.187	0.316	0.529	0.320	0.534	0.333	0.551	0.340	0.563	0.345	0.567	0.361	0.587	0.367	0.596
H	0.552	0.913	0.544	0.906	0.187	0.373	0.529	0.895	0.534	0.900	0.551	0.905	0.563	0.902	0.567	0.905	0.587	0.906	0.596	0.906

Note: high (H) En index in the green cells; medium (M) En index in the blue cells; and low (L) En index in the yellow cells.

Table A4
Index of Social pillar (So) of EU-28, 2005–2014.

Country	So_2005	So_2006	So_2007	So_2008	So_2009	So_2010	So_2011	So_2012	So_2013	So_2014
Austria	0.6633	0.6932	0.0852	0.5579	0.5618	0.5456	0.5723	0.5791	0.5671	0.597
Belgium	0.5135	0.5325	0.1449	0.4336	0.4331	0.4303	0.4372	0.4248	0.4117	0.4568
Bulgaria	0	0	0.1441	0	0	0	0	0	0	0.0653
Croatia	0.273	0.3258	0.1747	0.2224	0.2411	0.2294	0.2337	0.2433	0.2198	0.2242
Cyprus	0.2654	0.4364	0.1387	0.3836	0.395	0.3615	0.3663	0.3435	0.2902	0.3509
Czech Republic	0.4698	0.5331	0.0659	0.4758	0.4318	0.4192	0.4654	0.4486	0.4308	0.4247
Denmark	0.9253	0.9843	0.0305	0.8974	0.8504	0.8109	0.8394	0.8368	0.833	0.8194
Estonia	0.4323	0.5024	0.0095	0.4036	0.3607	0.4365	0.4379	0.4484	0.4104	0.3823
Finland	0.8575	0.8689	0.0415	0.7377	0.6978	0.7239	0.748	0.777	0.7768	0.7755
France	0.5357	0.5363	0.0737	0.4315	0.4129	0.4042	0.4176	0.4131	0.5872	0.6208
Germany	0.5545	0.5846	0.0776	0.4591	0.4469	0.4231	0.4498	0.4355	0.4255	0.4534
Greece	0.1619	0.2173	0.1485	0.1189	0.1281	0.0938	0.0671	0.0339	0.0223	0.0267
Hungary	0.4499	0.4376	0.178	0.3342	0.316	0.347	0.3374	0.2962	0.2528	0.2809
Ireland	0.4637	0.5069	0.1893	0.3082	0.2979	0.3238	0.348	0.3386	0.3642	0.366
Italy	0.2407	0.2327	0.2185	0.1086	0.1419	0.1175	0.1055	0.0974	0.0791	0.0985
Latvia	0.3523	0.3405	0.1346	0.2215	0.1365	0.1897	0.2293	0.2702	0.2638	0.267
Lithuania	0.3646	0.4369	0	0.33	0.3241	0.3019	0.3629	0.3579	0.3382	0.375
Luxembourg	0.5338	0.5624	0.0298	0.491	0.5268	0.5147	0.5406	0.5436	0.5271	0.5341
Malta	0.1688	0.2087	0.2122	0.1522	0.1627	0.1405	0.1384	0.1487	0.139	0.1589
Netherlands	0.7131	0.7629	0.0256	0.6768	0.6339	0.6152	0.616	0.6285	0.6354	0.6246
Poland	0.3153	0.3728	0.1735	0.3214	0.3038	0.2873	0.2776	0.271	0.2437	0.2796
Portugal	0.3909	0.4314	0.0799	0.3238	0.3456	0.3446	0.4043	0.3921	0.3366	0.3735
Romania	0.2201	0.2421	0.1619	0.1133	0.1113	0.0709	0.1005	0.0646	0.0352	0
Slovakia	0.3721	0.3958	0.1459	0.3348	0.3101	0.3061	0.3051	0.2905	0.297	0.3236
Slovenia	0.7154	0.7306	0.0599	0.6275	0.6239	0.6181	0.6124	0.5837	0.5293	0.5453
Spain	0.3459	0.3805	0.1761	0.2619	0.2533	0.279	0.3182	0.3076	0.3159	0.2999
Sweden	0.7594	0.7763	0.0283	0.7493	0.7088	0.7411	0.7641	0.7883	0.7576	0.8188
United Kingdom	0.6815	0.7313	0.2214	0.4866	0.5343	0.5188	0.5105	0.5053	0.5093	0.5161
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0
max	0.925	0.984	0.221	0.897	0.850	0.811	0.839	0.837	0.833	0.8194
mean	0.455	0.492	0.113	0.392	0.382	0.378	0.393	0.388	0.379	0.394957
sdv	0.219	0.219	0.068	0.211	0.203	0.204	0.209	0.215	0.220	0.219382
mean-0.5sdv	0.346	0.382	0.079	0.286	0.281	0.276	0.289	0.281	0.269	0.285266
mean+0.5sdv	0.564	0.601	0.147	0.497	0.483	0.480	0.497	0.496	0.488	0.504648

ranges	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*	*from*	*to*
L	0.000	0.346	0.000	0.382	0.000	0.079	0.000	0.286	0.000	0.281	0.000	0.276	0.000	0.289	0.000	0.281	0.000	0.269	0.000	0.285
M	0.346	0.564	0.382	0.601	0.079	0.147	0.286	0.497	0.281	0.483	0.276	0.480	0.289	0.497	0.281	0.496	0.269	0.488	0.285	0.505
H	0.564	0.925	0.601	0.984	0.147	0.221	0.497	0.897	0.483	0.850	0.480	0.811	0.497	0.839	0.496	0.837	0.488	0.833	0.505	0.819

Note: high (H) So index in the green cells; medium (M) So index in the blue cells; and low (L) So index in the yellow cells.

Table A5
Granger- causality test.

Variable	W&S	ISA	MAT	MAP
D. W&S		0.033 (1.87)*	0.109 (0.52)	−10.009 (2.35)**
D2. W&S	0.853 (13.21)***	−0.048 (2.64)**	0.001 (0.01)	1.519 (1.60)
D3. W&S	−0.230 (6.69)***	0.019 (3.07)***	−0.021 (0.27)	−9.616 (0.53)
D.MAT	0.212 (2.48)**	−0.025 (2.20)**		4.938 (1.40)
D2.MAT	−0.356 (3.74)***	0.019 (1.43)	0.879 (10.84)***	−9.920 (2.44)**
D3.MAT	0.133 (4.06)***	−0.005 (0.95)	−0.227 (5.26)***	2.917 (2.54)**
D.MAP	−0.001 (2.59)**	0.000 (0.85)	−0.000 (0.33)	
D2.MAP	0.001 (2.03)**	−0.000 (0.96)	0.001 (0.86)	0.845 (13.40)***
D3.MAP	−0.000 (1.38)	0.000 (1.11)	−0.000 (1.01)	−0.231 (7.16)***
D.ISA	0.620 (0.67)		−3.557 (2.63)**	6.733 (0.68)
D2.ISA	−0.581 (0.90)	0.560 (4.56)***	2.852 (2.97)***	−1.642 (1.02)
D3.ISA	0.044 (0.26)	0.018 (0.52)	−0.193 (0.75)	3.090 (0.85)
Temporal dummy	*yes*	*Yes*	*yes*	*yes*
Sargan test	*12.045*	*11.244*	*10.22*	*12.416*
Angrist-Pischke multivariate F test	*36.44***	*18.77***	*81.60***	*67.90***
GRANGER-CAUSALITY TEST				
Granger test (Wheat&Spelt)		3.81**	1.03	4.45***
Granger test (Sustainability Index)	0.29		3.02**	0.43
Granger test (MAT)	6.74***	2.59*		4.25***
Granger test (MAP)	2.77**	0.47	0.97	
R^2	0.94	0.88	0.94	0.93
N	104	104	104	104

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. T-statistics are in parenthesis. With D, D2, D3 we denote, respectively, the first, second, and third difference of the variables.

Table A6
Empirical results, GMM estimator.

Variable	W&S	ISA	MAT	MAP
L.W&S	0.979	−0.056	−0.178	−8.715
	(58.50)***	(9.44)***	(0.83)	(1.85)*
L2. W&S		−0.036	−0.303	−6.090
		(7.04)***	(0.65)	(7.38)***
L3. W&S		−0.028	0.482	−8.601
		(6.24)***	(1.05)	(3.24)***
L.MAT	−0.105	0.008	0.969	−5.607
	(2.31)**	(1.69)	(37.59)***	(5.50)***
L2.MAT	−0.141	−0.018		−2.690
	(2.40)**	(3.46)***		(2.68)**
L3.MAT	−0.029	−0.013		−6.503
	(0.42)	(2.14)**		(5.57)***
L.MAP	−0.000	−0.000	0.000	0.680
	(4.60)***	(1.25)	(0.49)	(14.15)***
L2.MAP	−0.000	−0.000	−0.000	
	(0.44)	(0.20)	(1.00)	
L3.MAP	−0.000	−0.000	0.000	
	(2.72)**	(0.64)	(1.32)	
L.ISA	−0.679	0.865	−0.307	−1.672
	(1.29)	(25.32)***	(2.45)***	(0.84)
L2. ISA	−0.415		−0.220	−1.967
	(0.35)		(4.64)***	(1.01)
L3. ISA	0.936		−0.524	−3.029
	(1.18)		(3.72)***	(0.28)
Constant	0.340	0.088	−0.518	0.094
	(1.28)	(2.29)**	(0.71)	(3.23)***
AR (1)	−2.09**	−2.10**	−2.06**	−2.04**
AR (2)	1.33	1.55	1.31	1.47
Sargan test	47.4	79.40	39.8	73.21
	[0.158]	[0.367]	[0.321]	[0.310]
Hansen test	42.79	78.34	34.54	75.80
	[0.672]	[0.430]	[0.374]	[0.507]
N	157	158	132	132

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. T-statistics are in parenthesis. P-values in []. With L, L2, L3 we denote, respectively, the first, second, and third lag of the variables.

References

Aaheim, A., Amundsen, H., Dokken, T., Ericson, T., Wei, T., 2009. A macroeconomic assessment of impacts and adaptation to climate change in Europe. Center for International Climate and Environmental Research Report.

Adams, M.R., Hurd, B.H., Lenhart, S., Leary, N., 1998. Effects of global climate change on agriculture: an interpretative review. Clim. Res. 11, 19–30.

Adger, W.N., 2006. Vulnerability. Glob. Environ. Change 16, 268–281.

Agovino, M., 2014. What are the main explanations of occupational diseases and accidents at work in the agricultural sector? A panel analysis for Italian regional data. Quality Quantity 48 (2), 1045–1073.

Agovino, M., Aldieri, L., Garofalo, A., Vinci, C.P., 2017. Quality and quantity in the innovation process of firms: a statistical approach. Quality Quantity 51 (4), 1579–1591.

Akcali, B.Y., Sismanoglu, E., 2015. Innovation and the effect of research and development (R&D) expenditure on growth in some developing and developed countries. Procedia 195, 768–775.

Arellano, M., Bover, O., 1995. Another look at the instrumental-variable estimation of error-components models". J. Econometrics 68, 29–52.

Arellano, M., Bond, S.R., 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev. Econ. Stud. 58, 277–297.

Bale, J.S., van Lenteren, J.C., Bigler, F., 2008. Biological control and sustainable food production. Phil. Trans. R. Soc. B. 363, 761–776. http://dx.doi.org/10.1098/rstb.2007.2182.

Betcherman, G., 2015. Jobs and Sustainable Development: How do Labor Policies and Institutions fit in? Expert Group Meeting on Strengthening Social Development in the Contemporary World organized by the Division for Social Policy and Development, UN-DESA in New York on May 19-20, 2015.

Bley, S. J., Hametner, M., Dimitrova, A., Ruech, R., De Rocchi, A., Gschwend, E., Umpfenbach, K., 2017. Smarter, greener, more inclusive? Indicators to support the Europe 2020 strategy-2017 edition Luxembourg: Publications Office of the European Union, 2017.

Blundell, R.W., Bond, S.R., 1998. Initial conditions and moment restrictions in dynamic panel data models. J. Econometrics 87, 115–143.

Brethour, C., Weerskink, A., 2001. An economic evaluation of the environmental benefits from pesticide reduction. Agric. Econ. 25, 219–226. http://dx.doi.org/10.1111/j.1574-0862.2001.tb00202.x.

Campbell, B.R., Thornton, P., Zougmoré, R., van Asten, P., Lipper, L., 2014. Curr. Opin. Environ. Sustain. 8, 39–43.

Choe, J.I., 2003. Do foreign direct investment and gross domestic investment promote economic growth? Rev. Dev. Econ. 7, 44–57.

Ciscar, J., Iglesias, C., Feyen, A., Szabóa, L., Regemortera, L., Van Amelunge, D., Nicholls g, B., Watkissh, R., Christenseni, P., Dankersc, O.B., Garrotek, R., Goodessl, L., Huntm, C.M., Morenoe, A., Richards, A., Sori, J., 2011. Physical and economic consequences of climate change in Europe. PNAS 108 (7), 2678–2683.

Crociata, A., Agovino, M., Russo, A., Quaglieri Dominiguez, A., 2015. Creative workforce and economic development in precrisis Europe. Main trends and causality relationships. Int. Reg. Sci. Rev. http://dx.doi.org/10.1177/0160017615607054.

Cromwell, J.B., Labys, W.C., Hannan, M.J., Terrazza, M., 1994. Multivariate Tests for Time Series Models, Issue 100. Sage University.

Davis, B., Winters, P., 2010. A cross-country comparison of rural income generating activities. World Dev. 38 (1), 48–63.

Delmas, R., Serca, D., Jambert, C., 1997. Global inventory of NOx sources. Nutr. Cycl. Agroecosyst. 48, 51–60.

Dietrich, A., 2012. Does growth cause structural change, or is it the other way around? A dynamic panel data analysis for seven OECD countries. Emp. Econ. 43, 915–944.

Elder, S., 2015. What does NEETs mean and why is the concept so easily misinterpreted? International Labor Office.

Eurofound, 2016. The gender employment gap: Challenges and solutions. Publications Office of the European Union, Luxembourg.

European Commission (EC), 2012. The multifunctionality of Green Infrastructure; European Commission. Available from: http://ec.europa.eu/environment/nature/ecosystems/docs/Green_Infrastructure.pdf.

European Commission, 2012. The common agricultural policy. A story to be continued.

http://ec.europa.eu/agriculture/50-years-of-cap/files/history/history_book_lr_en.pdf (Last access 26th June 2017).
European Commission (EC), 2016. http://ec.europa.eu/environment/archives/eussd/index.htm (last access May 24th, 2017).
European Commission. 2017. https://ec.europa.eu/europeaid/sectors/food-and-agriculture/sustainable-agriculture-and-rural-development/agricultural-development_en (Last access 20th June 2017).
European Union Committee, 2010. Adapting to climate change: EU agriculture and forestry. 8th Report of Session 2009–10, Volume I: Report, Authority of the House of Lords, London. Available from: https://publications.parliament.uk/pa/ld200910/ldselect/ldeucom/91/91i.pdf.
EUROSTAT, 2016a. Europe 2020 Strategy. Positive developments since 2008 in the EU on education, climate change and energy...but limited or no progress for employment, poverty and R&D. Eurostat Newsrelease145/2016.
EUROSTAT, 2016b. Agriculture, forestry and fishery statistics – 2016 edition.
EUROSTAT, 2017. http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Final_energy_consumption (last access May, 2017).
FAO, 2013. Food and Agricultural Oraganization of the United Nations: Climate Smart Agricultural Sourcebook. Available from: http://www.fao.org/3/a-i3325e.pdf.
Florek, K., Łukaszewicz, J., Perkal, J., Steinhaus, H., Zubrzycki, S., 1951. Taksonomia wrocławska. Przegląd Antropologiczny 17, 193–211.
Füssel, H.M., 2007. Vulnerability: a generally applicable conceptual framework for climate change research. Glob. Environ. Change 17, 155–167.
Gatzweiler, F., Hagedorn, K., 2002. The Evolution of Institutions of Sustainability in Transition. In: F. Gatzweiler, R. Judis, K. Hagedorn (eds.), Sustainable Agriculture in Central and Eastern European Countries – Institutional Change in Agriculture and Natural Resources 10, P. 3-16. Aachen.
Gliessman, S.R., 2005. Agroecology and agroecosystems. In: Pretty, J. (Ed.), The earthscan reader in sustainable agriculture. Earthscan, London, UK ISBN: 978-1-84407-236-1.
Gliessman, S.R., 2015. Agroecology: The Ecology of Sustainable Food Systems, third eds. Taylor & Francis Group, LLC, Boca Raton FL.
Goulding, K., Jarvis, S., Whitmore, A., 2008. Optimizing nutrient management for farm systems. Philos. Trans. R. Soc. London, Ser. B 363 (1491), 667–680.
Granger, C., 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica 37 (3).
Hall, N.M., Bocary, K., Janet, D., Ute, S., Amadou, N., Tobo, R., 2006. Effect of improved fallow on crop productivity, soil fertility and climate-forcing gas emissions in semi-arid conditions. Biol. Fertil. Soils 42, 224–230.
Hall, S.J., Matson, P.A., Roth, P., 1996. NOx emission from soil: implications for air quality modeling in agricultural regions. Annu. Rev. Energy Environ. 21, 311–346.
Hamilton, J., 1995. Econometria delle serie storiche. Monduzzi Editore, Bologna.
Happo, M.S., Uski, O., Jalava, P.I., Kelz, J., Brunner, T., Hakulinen, P., Mäki-Paakkanen, J., Kosma, V., Jokiniemi, J., Obernberger, I., Hirvonen, M., 2013. Pulmonary inflammation and tissue damage in the mouse lung after expo- sure to PM samples from biomass heating appliances of old and modern technologies. Sci. Total Environ. 443, 256–266.
Harbison, F.H., Maruhnic, J., Resnick, J.R., 1970. Quantitative Analyses of Modernization and Development. Princeton University Press, Princeton.
Hassanali, A., Herren, H., Khan, Z.R., Pickett, J.A., Woodcock, C.M., 2008. Integrated pest management: the push-pull approach for controlling insect pests and weeds of cereals, and its potential for other agricultural systems including animal husbandry. Phil. Trans. R. Soc. B. 363, 611–621.
Holtz-Eakin, D., Newey, W., Rosen, H., 1988. Estimating vector autoregressions with panel data. Econometrica 56, 1371–1395.
Hoover, K., 2001. Causality in Macroeconomics. Cambridge University Press.
Hsiao, C., 1986. Analysis of panel data. Cambridge University Press, Cambridge.
Ignaciuk, A., Mason-D'Croz, D., 2014. Modelling Adaptation to Climate Change in Agriculture, OECD Food, Agriculture and Fisheries Papers, No. 70. OECD Publishing, Paris.
IEA, 2017. https://www.iea.org/about/faqs/coal/ (last access May, 2017).
ILO, 2014. World of Work Report 2014: Developing with Jobs. ILO, Geneva.
Kim, K., Jahan, S.A., Kabir, E., Brown, R.J.C., 2013. A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects. Environ. Int. 60, 71–80.
Kliucininkas, L., Krugly, E., Stasiulaitiene, I., Radziuniene, I., Prasauskas, T., Jonusas, A., Kauneliene, V., Martuzevicius, D., 2014. Indoor-outdoor levels of size segregated particulate matter and mono/polycyclic aromatic hydrocarbons among urban areas using solid fuels for heating. Atmos. Environ. 97, 83–93.
Leamer, E., 1985. Vector Autoregressions for Causal Inference?, in K. Brunner, A.H. Meltzer (a cura di), Understanding Monetary Regime, Carnegie-Rochester Conference Series on Public Policy, 22, pp. 255–304.
Lewis, W.J., van Lenteren, J.C., Phatak, S.C., Tumlinson, J.H.I.I.I., 1997. Total system approach to sustainable pest management. Proc. Natl. Acad. Sci. U.S.A. 94 (23), 12243–12248.
Lin, B., 2011. Resilience in agriculture through crop diversification: adaptive management for environmental change. BioScience 61 (3), 183–193.
Maleksaeidi, H., Karami, E., 2012. Social-ecological resilience and sustainable agriculture under water scarcity. Agroecol. Sustain. Food Syst. 37 (3), 262–290.
Mazziotta, M., Pareto, A., 2017. Synthesis of indicators: the composite indicators approach. In: Maggino, F. (Ed.), Complexity in Society: From Indicators Construction to their Synthesis. Social Indicators Research Series, vol 70. Springer, Cham.
McIntyre, B.D., Herren, H.R., Wakhungu, J., Watson, R.T., 2009. Agriculture at a Crossroads: The Global Report. The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). ISBN: 9781597265386.
Millar, J., Ridge, T., 2009. Relationship of care: working lone mothers, their children and employment sustainability. J. Social Policy 38 (1), 103–121.
Nair-Reichert, U., Weinhold, D., 2001. Causality tests for cross-country panels: a new look at FDI and economic growth in developing countries. Oxf. Bull. Econ. Stat. 63, 153–171.
Nelson, G., Rosegrant, M., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M., Lee, D., 2009. Climate Change: Impact on Agriculture and Costs of Adaptation. IFPRI, Washington DC.
Neves, A.R., Leal, V., 2010. Energy sustainability indicators for local energy planning: Review of current practices and derivation of new framework. Renewable Sustainable Energy Rev. 14, 2723–2735.
NIACE 2015. Adult Participation in Learning Survey: Headline Findings. http://www.learningandwork.org.uk/sites/niace_en/files/resources/2015%20Adult%20Participation%20in%20Learning%20-%20Headline%20Findings.pdf?redirectedfrom=niace (last access May, 2017).
OECD, 2008. Handbook on constructing composite indicators: Methodology and User guide. Joint Research Centre-European Commission, OECD publishing.
OECD, 2012. Farmer Behaviour, Agricultural Management and Climate Change; http://www.oecd-ilibrary.org/agriculture-and-food/farmer-behaviour-agricultural-management-and-climate-change_9789264167650-en (last access December 2017).
OECD, 2016a. Agriculture and Climate Change: Towards Sustainable, Productive and Climate-Friendly Agricultural Systems. OECD Meeting of Agriculture Ministers, Bachground note. Available from: https://www.oecd.org/tad/sustainable-agriculture/4_background_note.pdf.
OECD, 2016b. Towards Sustainable, Productive and Climate Friendly Agricultural Systems, Agriculture Policy Note. Available from: https://www.oecd.org/tad/policynotes/sustainable-productive-climate-friendly-agricultural-systems.pdf.
Pérez-Lombard, L., Ortiz, J., Pout, C., 2008. A review on buildings energy consumption information. Energy Build. 40, 394–398.
Petersen, J.E., Feehan, J., 2003. Agri-environmental programmes and the candidate countries. In: International Conference on EU: CAP and Enlargement - an opportunity for nature and environment, Ecologica Berlin 19–21.
Porter, J.R., Gawith, M., 1999. Temperatures and the growth and development of wheat: a review. Eur. J. Agron. 1999 (10), 23–36.
Prager, K., 2015. Agri-environmental collaboratives for landscape management in Europe. Curr. Opin. Environ. Sustain. 12, 59–62.
Pretty, J., 1995. Regenerating agriculture: policies and practice for sustainability and self-reliance. Earthscan; National Academy Press, London, UK, Washington, DC.
Pretty, J., 2008. Agricultural sustainability: concepts, principles and evidence. Philos. Trans. R. Soc. London, Ser. B.
Pretty, J., Brett, C., Gee, D., Hine, R., Mason, C.F., Morison, J.I.L., Raven, H., Rayment, M., van der Bijl, G., 2000. An assessment of the total external costs of UK agriculture. Agric. Syst. 65, 113–136.
Pretty, J., Mason, C.F., Nedwell, D.B., Hine, R.E., 2003. Environmental costs of freshwater eutrophication in England and Wales. Environ. Sci. Technol. 37, 201–208. http://dx.doi.org/10.1021/es020793k.
Samuel, K., Uwizeyimana, J.B., 2017. Social Connectedness and Poverty Eradication: A South African Perspercive. CROP Publications. Available from: http://www.crop.org/Publications/Working-Paper-Series/Social-Connectedness-and-Poverty-Eradiation-A-South-African-Perspective.aspx.
Sands, Gary R., Podmore, Terence H., 2000. A generalized environmental sustainability index for agricultural systems. Agric. Ecosyst. Environ. 79 (1), 29–41.
Scherr, S.J., McNeely, J.A., 2008. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. Philos. Trans. R. Soc. London, Ser. B 363, 477–494.
Silvio-Pomenta, J.F., 1973. Typological study using the Wroclaw Taxonomic Method (A study of regional disparities in Venezuela). SHC/WS/316, UNESCO, Paris.
Smith, C.S., McDonald, G.T., 1998. Assessing the sustainability of agriculture at the planning stage. J. Environ. Manage. 52 (1), 15–37.
Smith, J.B., Huq, S., Lenhart, S., Mata, L.J., Nemesova, I., Toure, S., 1996. Vulnerability and adaptation to climate change: a synthesis of results from the U.S. Country Studies Program. Kluwer Academic Publishers, Dordrecht.
SOLID FUEL ASSOCIATION, 2017. http://www.nwleics.gov.uk/files/documents/guide_to_solid_fuels/solid%255Ffuels%252Epdf.pdf (last access May, 2017).
Stokes, C.J., Howden, M., 2010. Adapting Agriculture to Climate Change: Preparing Australian agriculture, forestry and fisheries for the future. CSIRO Publishing, Melbourne.
Sustainable Development, 2001. A summary report from the workshop on poverty alleviation and sustainable development. International Institute for Sustainable Development.
Tampakoudis, I.A., Fylantzopoulou, D., Nikandrou, K., 2014. Examining the Linkages between GDP Growth and Sustainable Development in the Eurozone. J. Econ. Bus. XVII, 2.
Tebaldi, C., Lobell, D.B., 2008. Towards probabilistic projections of climate change impacts on global crop yields. Geophys. Res. Lett. 35, 8. http://dx.doi.org/10.1029/2008GL033423.
Tilman, E., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418, 617–677.
Tisdell, C.A., 1996. Agricultural sustainability and the environment: Issues and strategies with particular reference to India and Australia. Vol. 1 In: Roy, K.C., Sen, R.K., Tisdell, C.A. (Eds.), Environment and Agricultural Development-Concepts, General Issues, Constraints and Strategies. New Age International Publishers.
UNSD, 1992. United Nations Conference on Environment & Development Rio de Janerio, Brazil, 3 to 14 June 1992. Available from: https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.

Uthes, S., Piorr, A., Zander, P., Bienkowski, J., Ungaro, F., Dalgaard, T., Stolze, M., Moschitz, H., Schader, C., Happe, K., Sahrbacher, A., Damgaard, M., Toussaint, V., Sattler, C., Reinhardt, F.J., Kjeldsen, C., Casini, L., Müller, K., 2011. Regional impacts of abolishing direct payments: an integrated analysis in four European regions. Agric. Syst. 104, 110–121.

Vandermeer, J., van Noordwijk, M., Anderson, J., Ong, C., Perfecto, I., 1998. Global change and multi-species agroecosystems: concepts and issues. Agric. Ecosyst. Environ. 67, 1–22.

Venkataraman, B., 2009. Available from: http://jtimes.ca/water/wp-content/uploads/2015/05/Education-for-Sustainable-Development.pdf.

Victor, T.J., Reuben, R., 2002. Effects of organic and inorganic fertilizers on mosquito populations in rice fields of southern India. Med. Vet. Entomol. 14, 361–368.

Von Wirén-Lehr, S., 2001. Sustainability in agriculture – an evaluation of principal goal-oriented concept to close the gap between theory and practice. Agric. Ecosyst. Environ. 84 (2), 115–129.

Waggoner, P.E., 1983. In: Agriculture and a Climate Changed by More Carbon Dioxide. Changing climate. National Academy Press, Washington, DC, pp. 383–418.

Wassmann, R., Jagadish, S.V.K., Heur, S., Ismail, A., Redona, E., Serraj, R., Singh, R.K., Howell, H., Pathak, G., Sumfleth, K., 2009. Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. In: Sparks, D.L. (Ed.), Advances in Agronomy. Elsevier Science, Amsterdam, The Netherlands Vol. 101.

WCED, 2007. From one earth to one world. In: Dryzek, J., Schlosberg, D. (Eds.), Debating the Earth: The Environmental Politics Reader, second ed. Oxford University Press, Great Britain, pp. 259–267.

Weinhold, D., 1996. Investment, growth and causality testing in panels. Econ. Previs. 126, 163–175.

Welch, J.R., Vincent, J.R., Auffhammer, M., Moya, P.F., Dobermann, A., Dawe, D., 2010. Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. Proc. Natl. Acad. Sci. 107, 14562–14567.

Zalidis, G.C., Tsiafouli, M.A., Takavakoglou, V., Bilas, G., Misopolinos, N., 2004. Selecting agri-environmental indicators to facilitate monitoring and assessment of EU agri-environmental measures effectiveness. J. Environ. Manage. 70 (4), 315–321.